



PRINCETON
Neuroscience
INSTITUTE



quantifying the interaction between mood and reward (& attention)

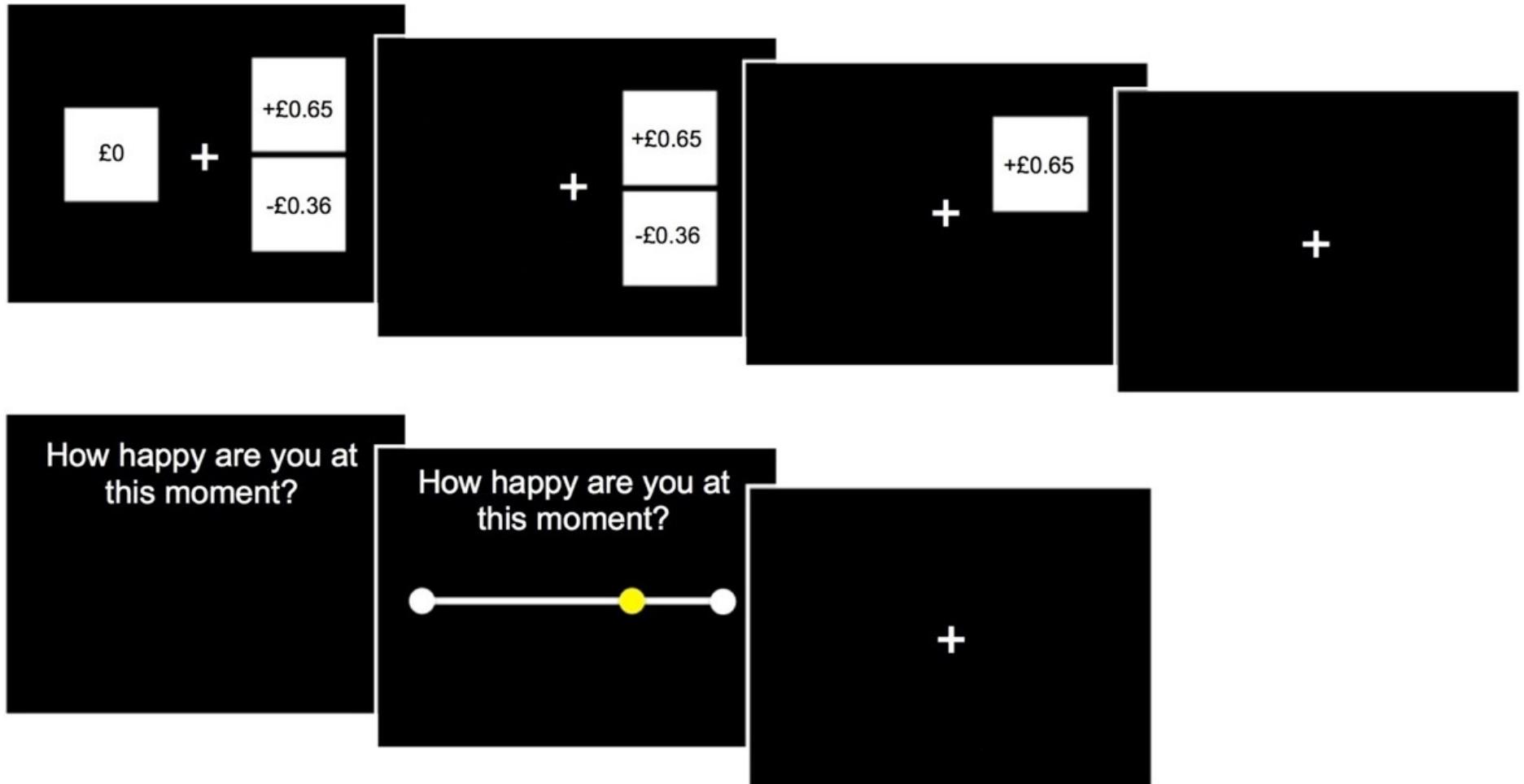
Yael Niv, PhD (yael@princeton.edu)

Psychology Department & Princeton Neuroscience Institute, co-director CCNP



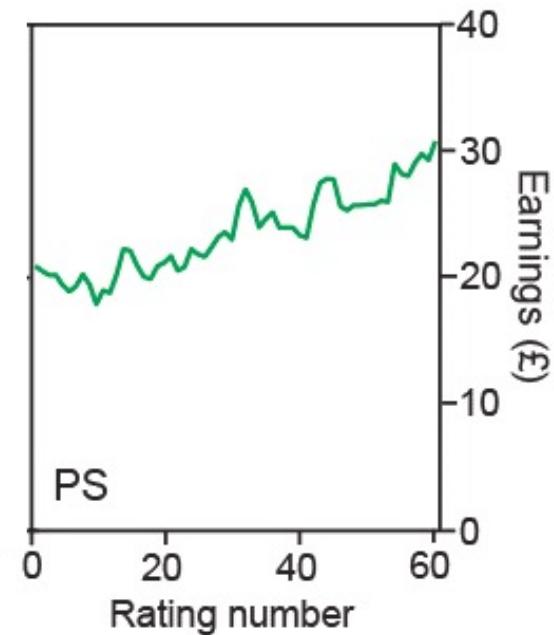
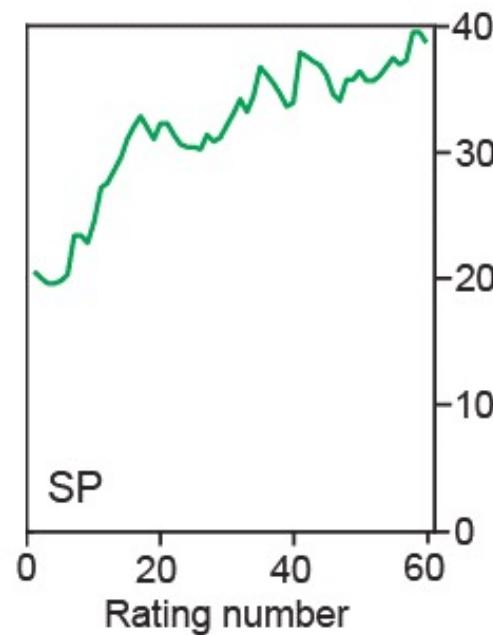
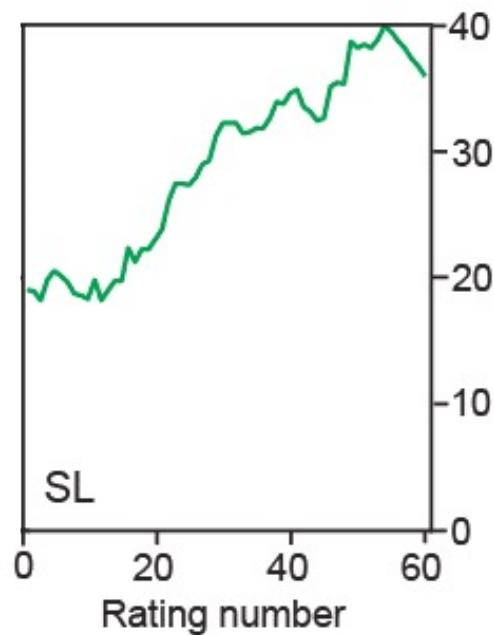
Rutgers-Princeton Center for
Computational **Cognitive Neuro-Psychiatry**

What makes us happy?

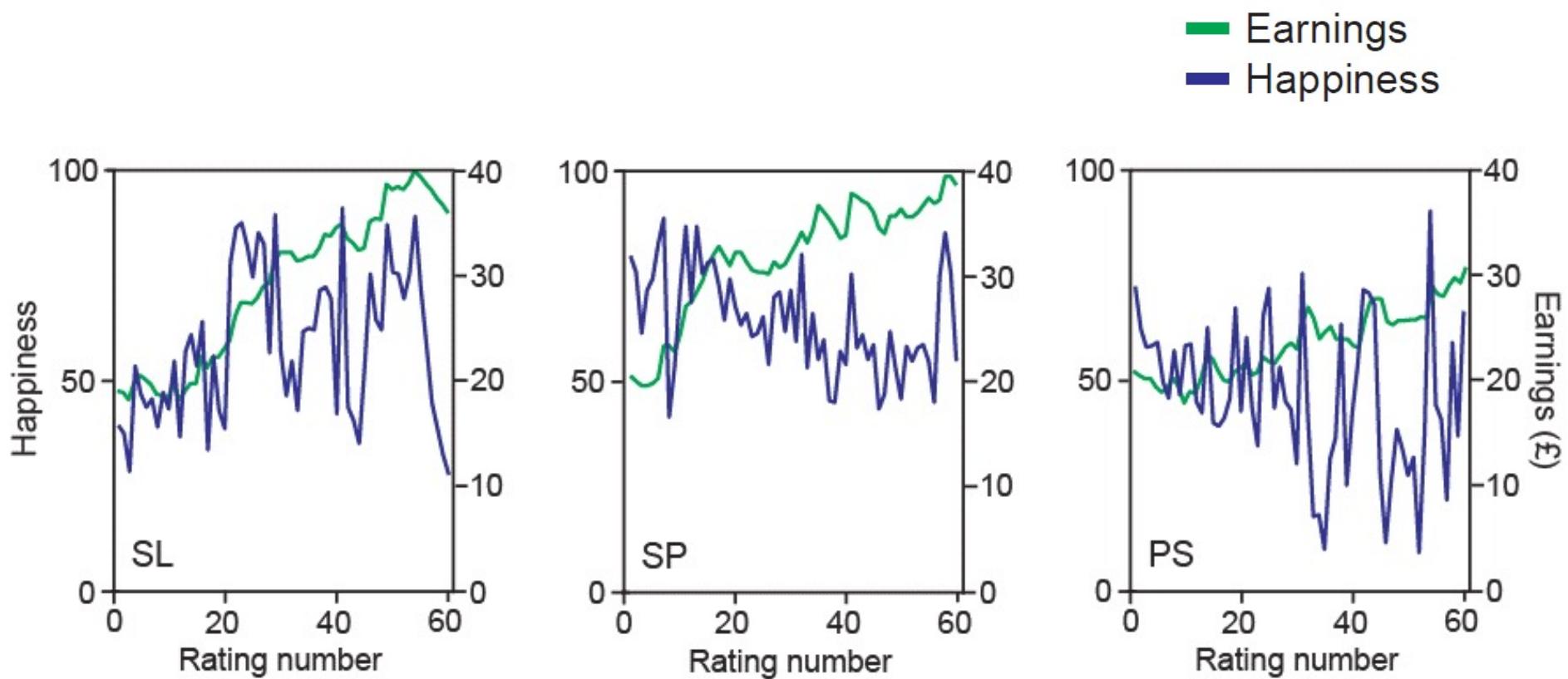


What makes us happy?

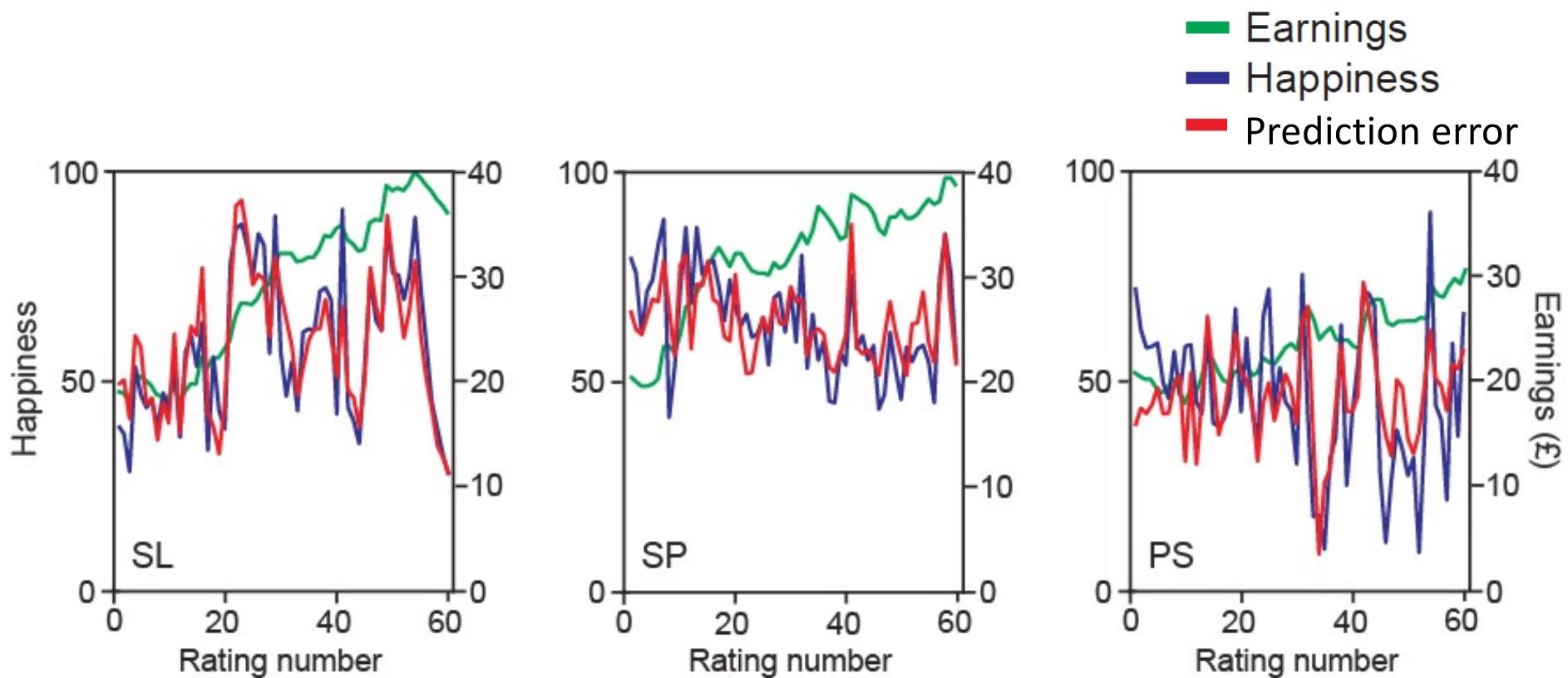
Earnings
Happiness



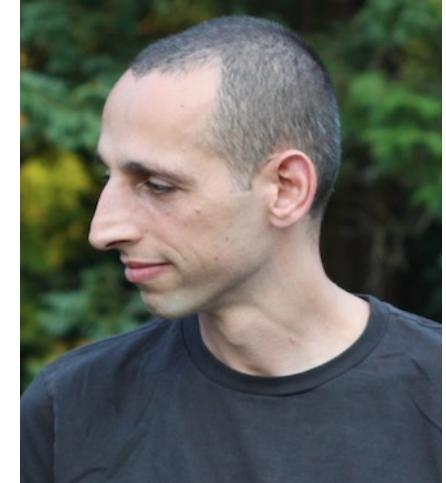
What makes us happy?



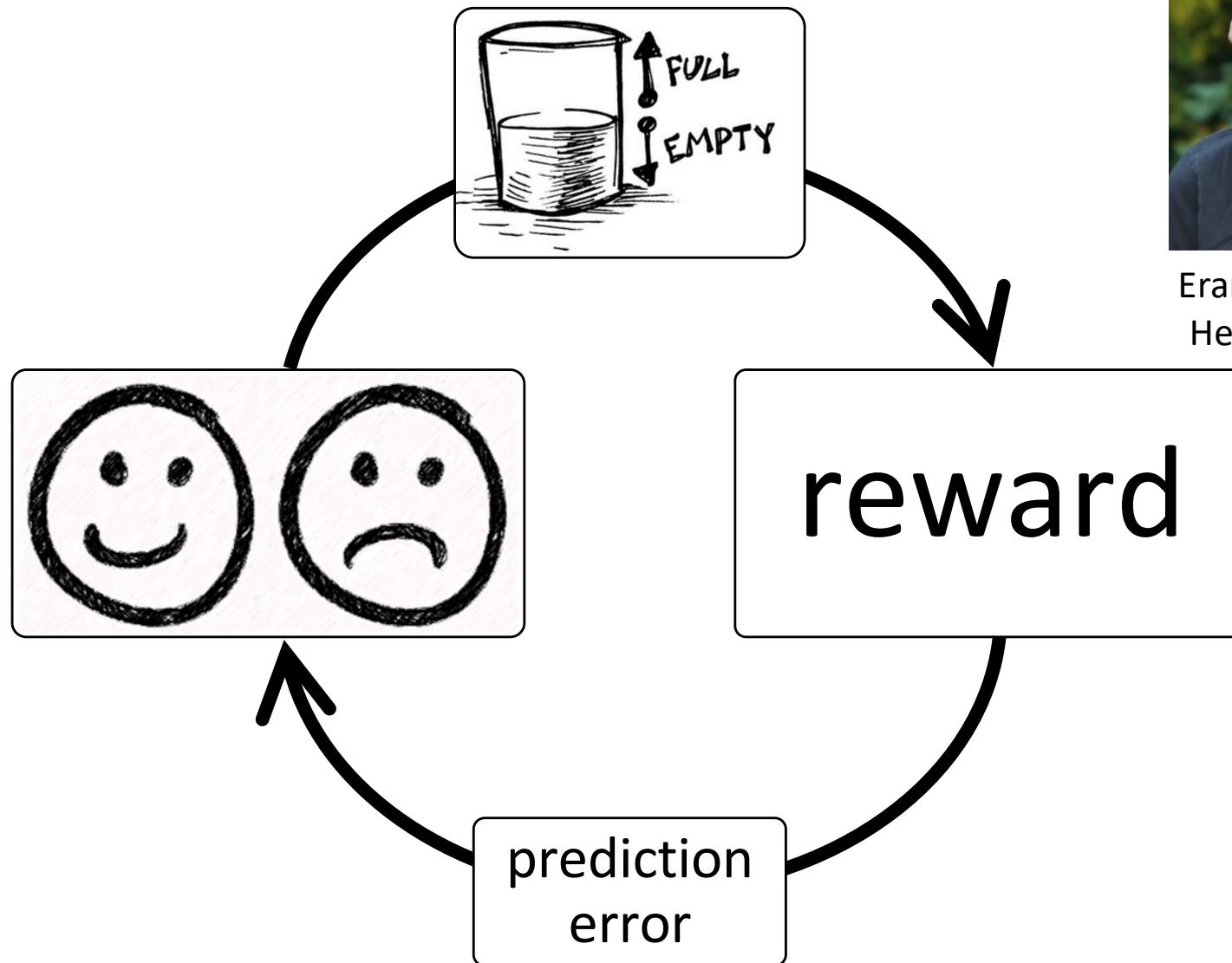
What makes us happy?



(momentary) happiness depends
not on how much you are making, but on
how much you are making relative to your expectations



Eran Eldar, MD, PhD
Hebrew University



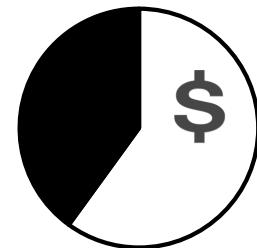
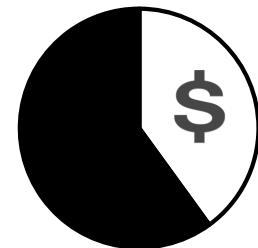
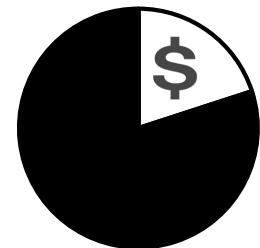
game 1



game 1



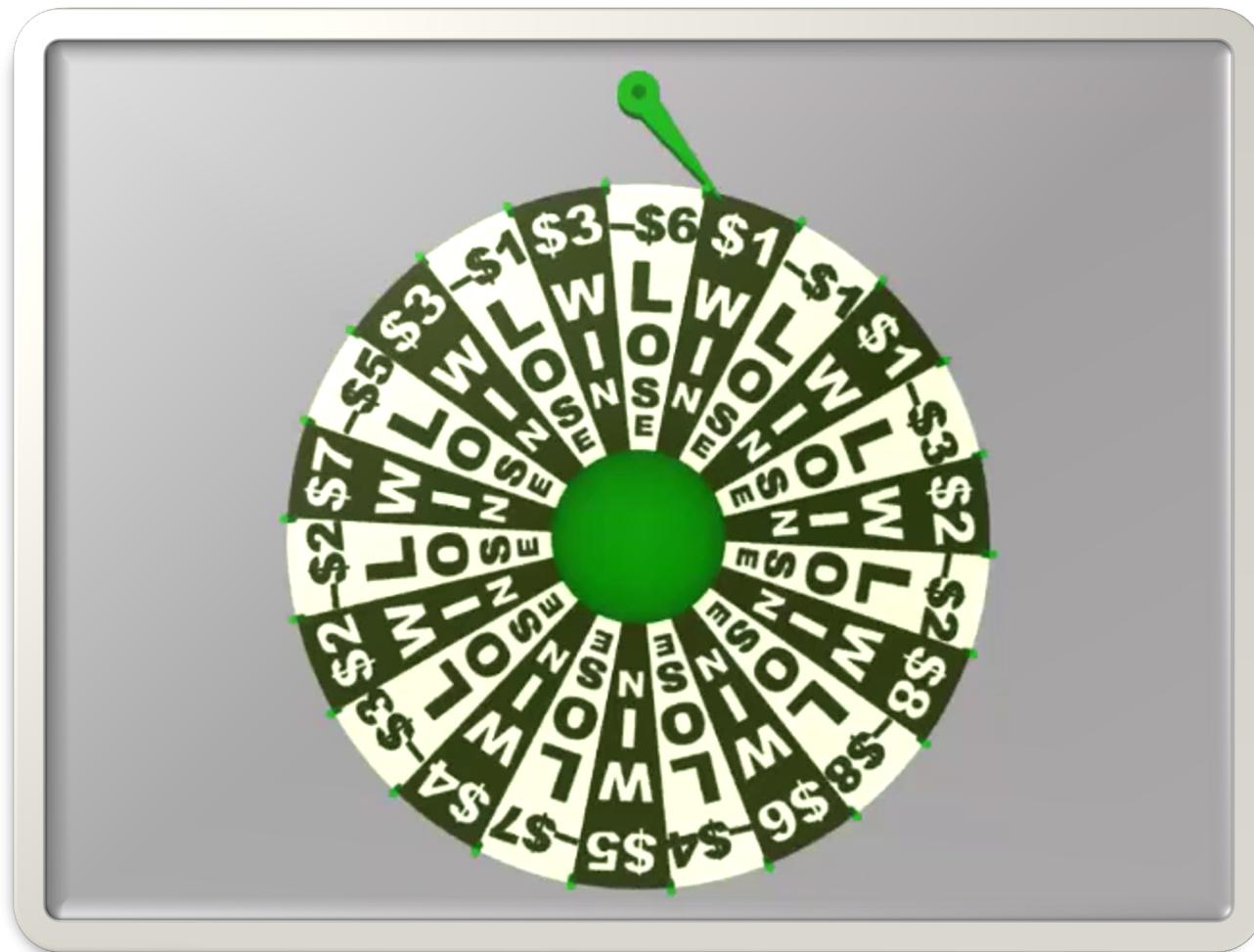
game 1

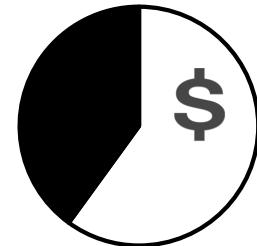
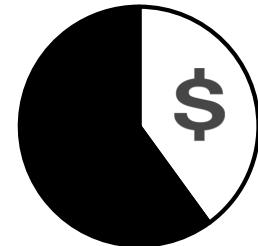
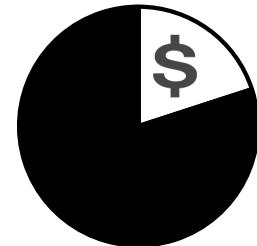
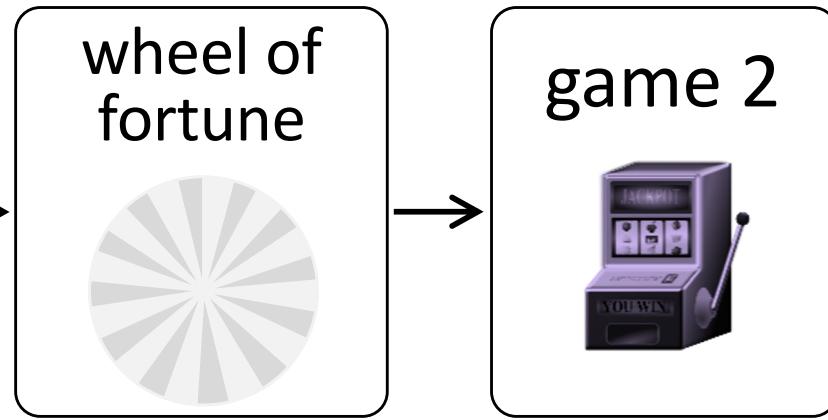


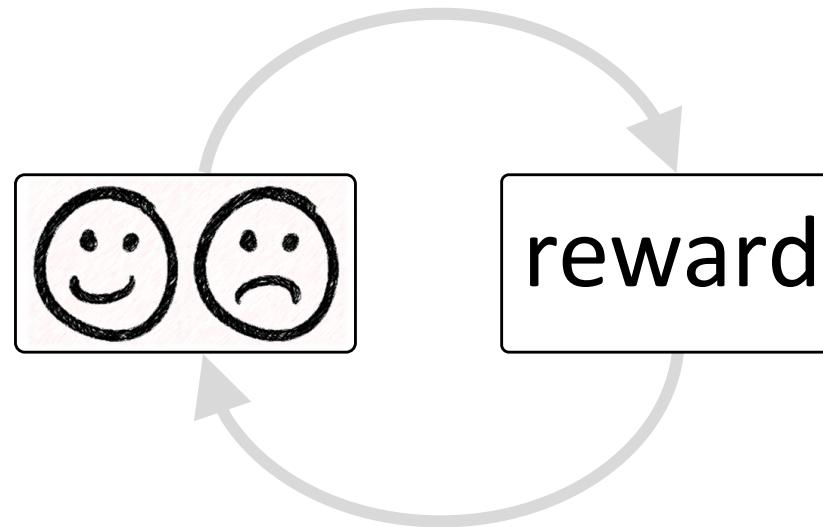
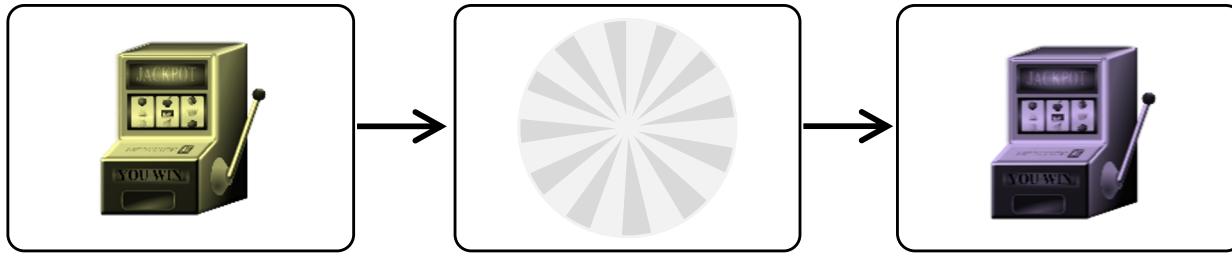
game 1

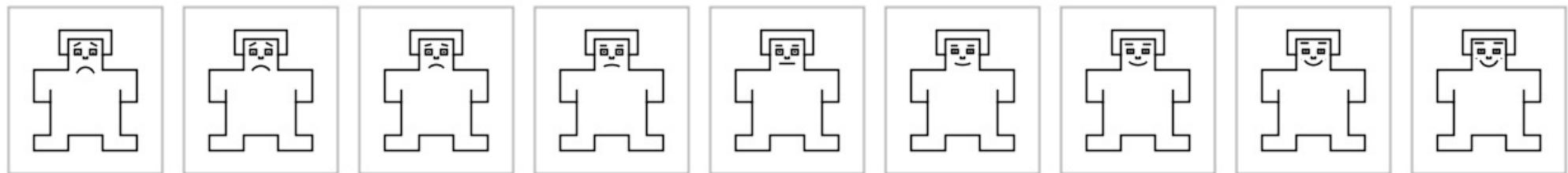
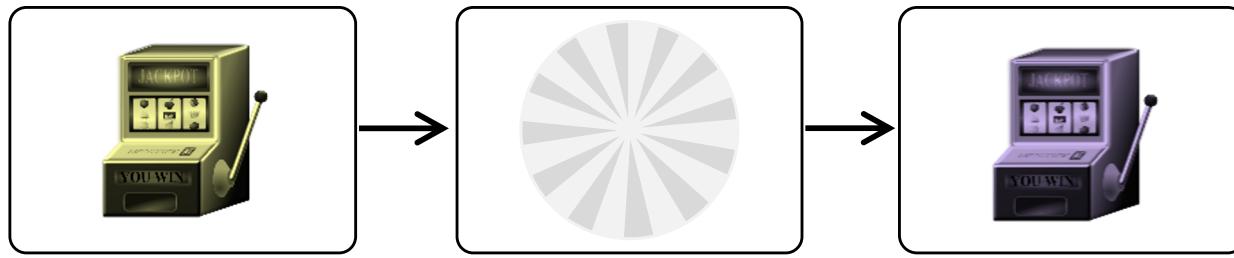


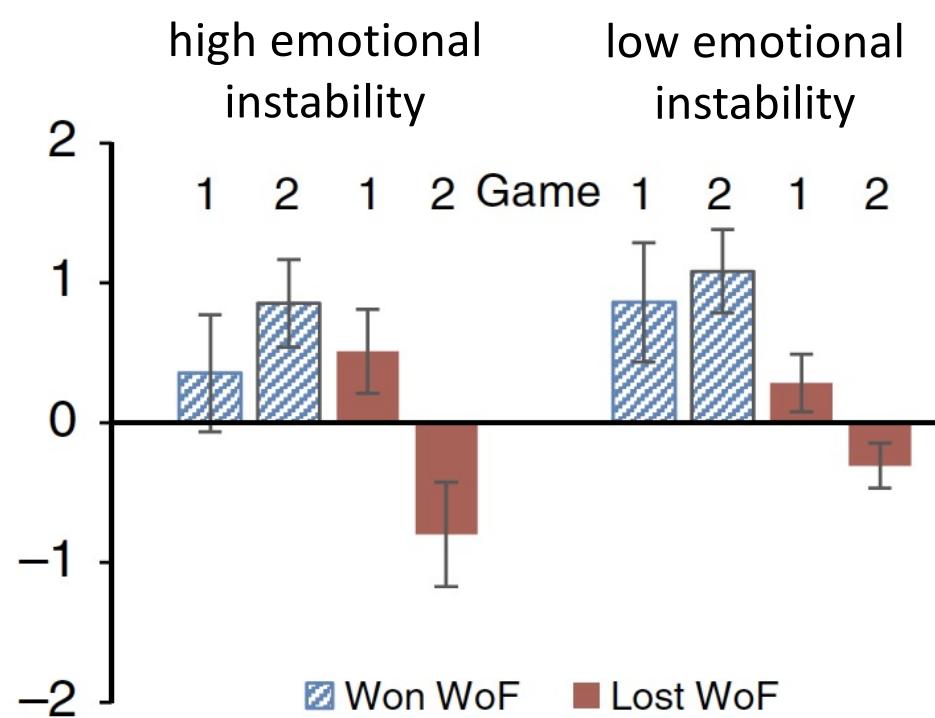
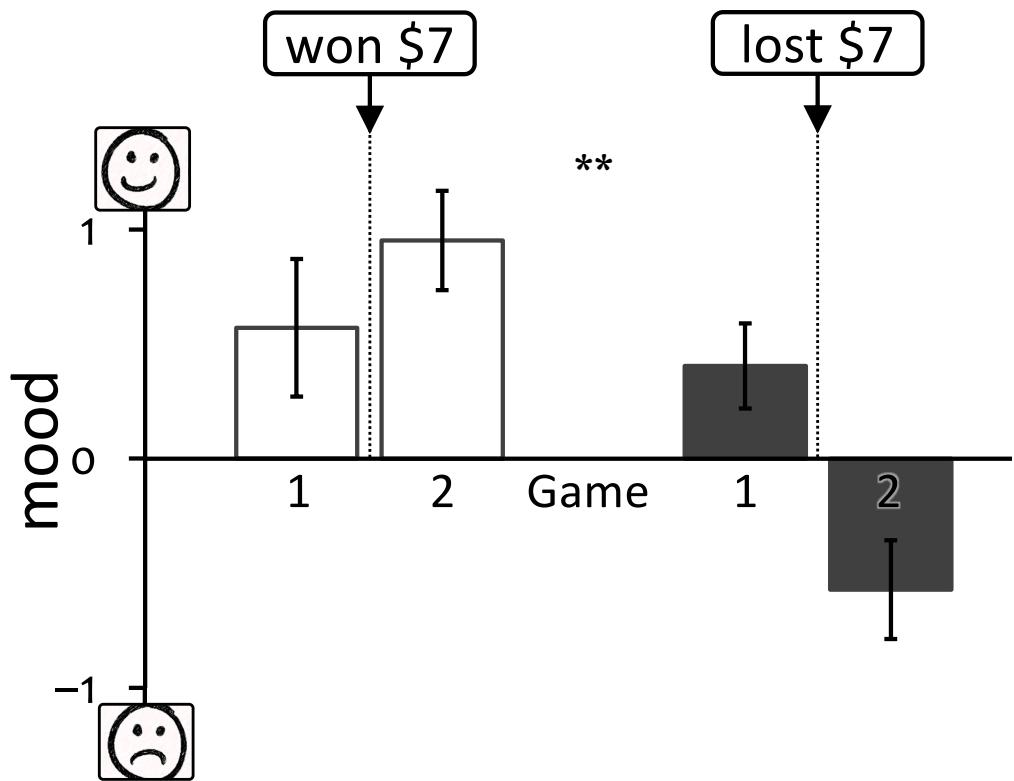
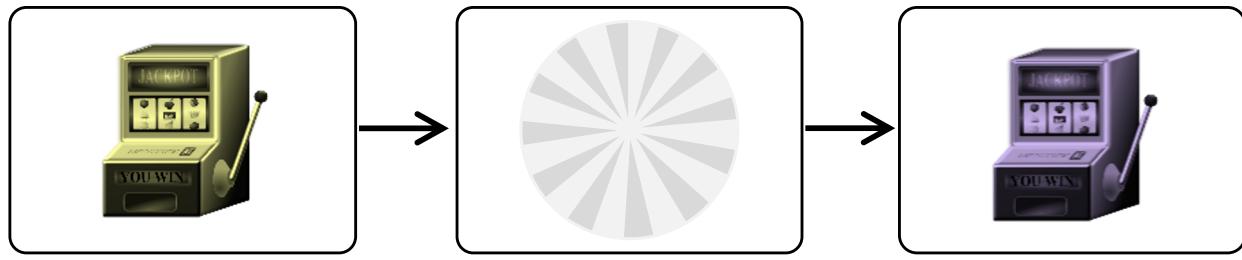
wheel of
fortune

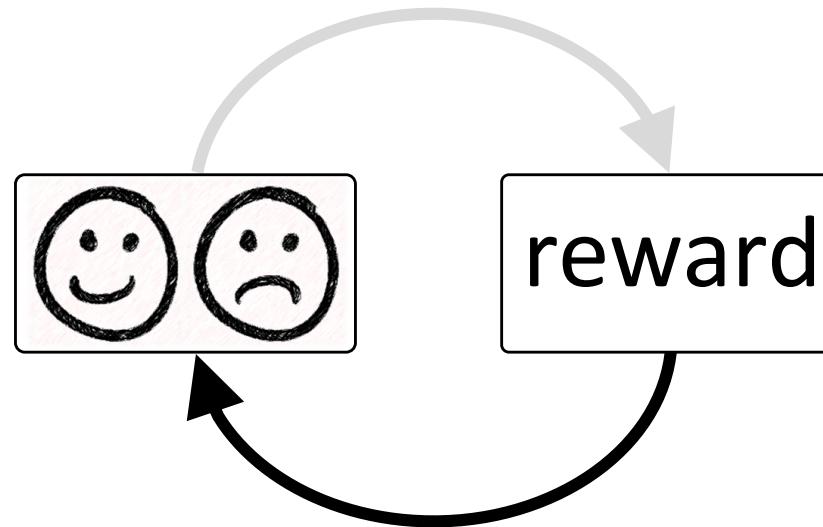
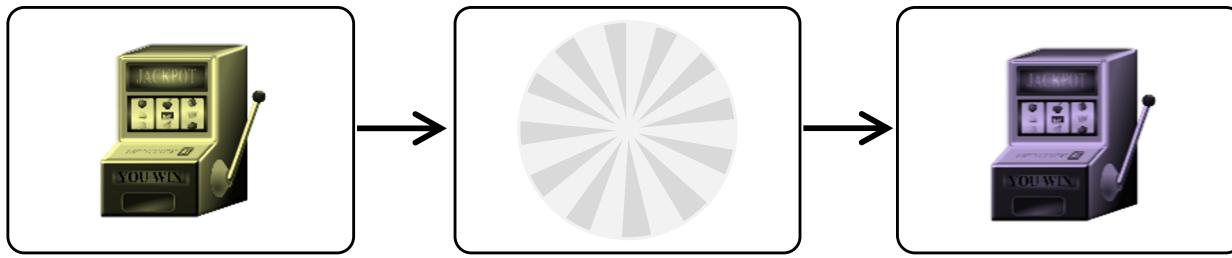


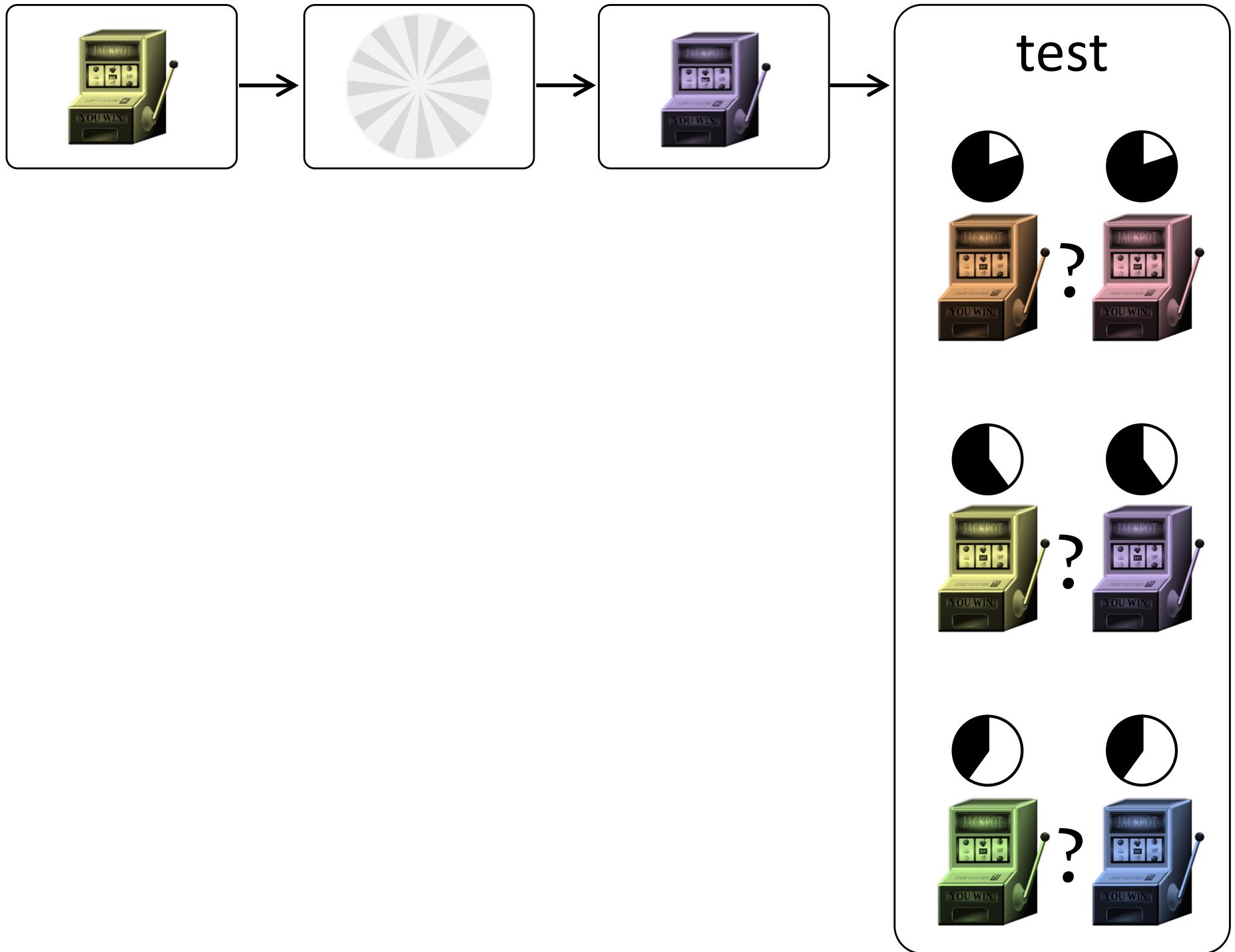


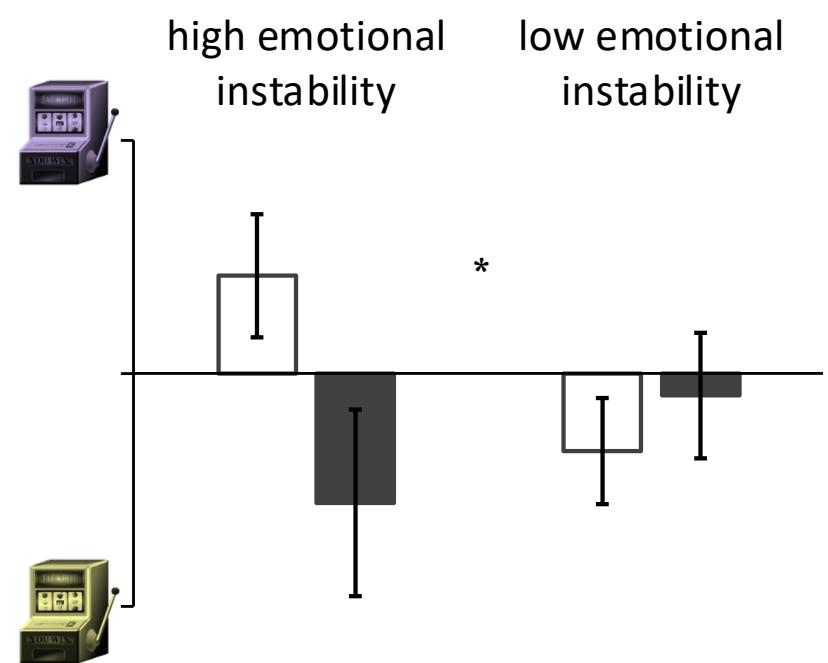
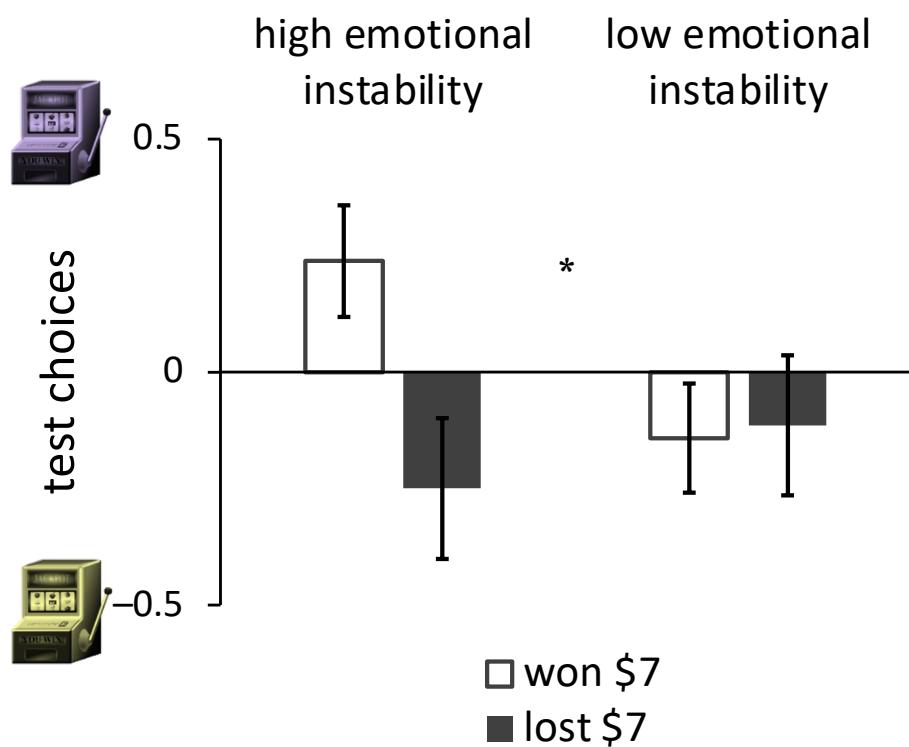
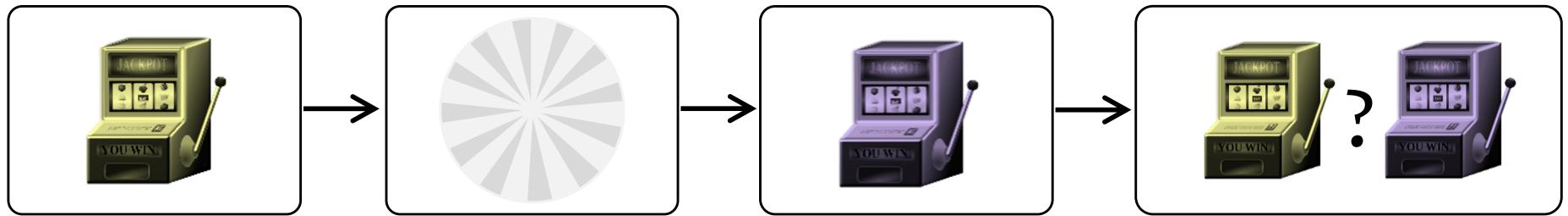


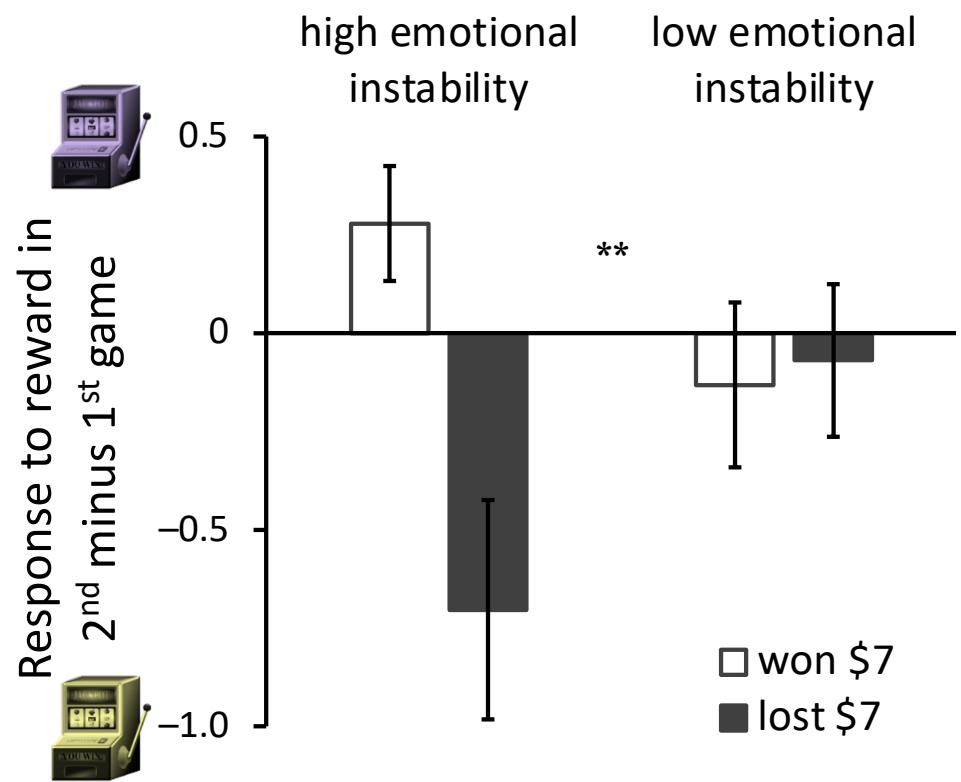
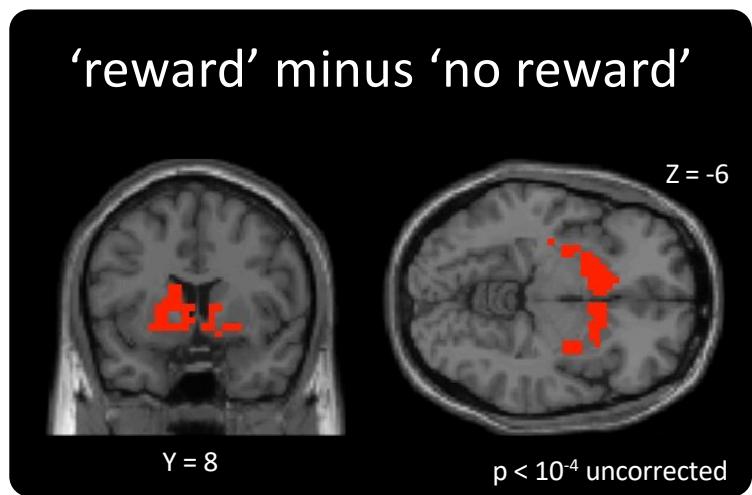
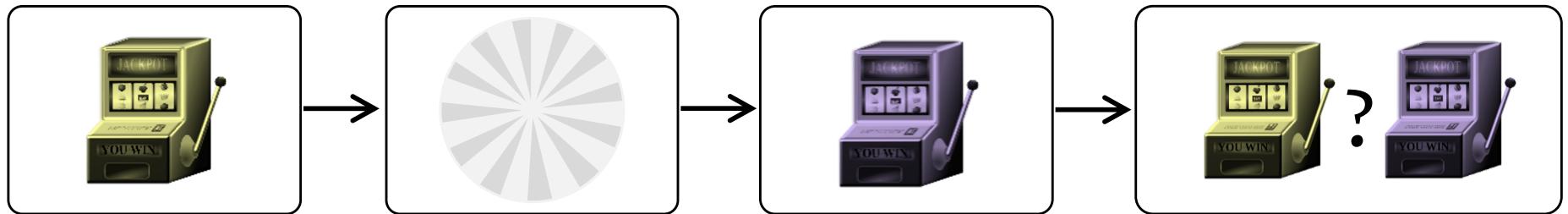






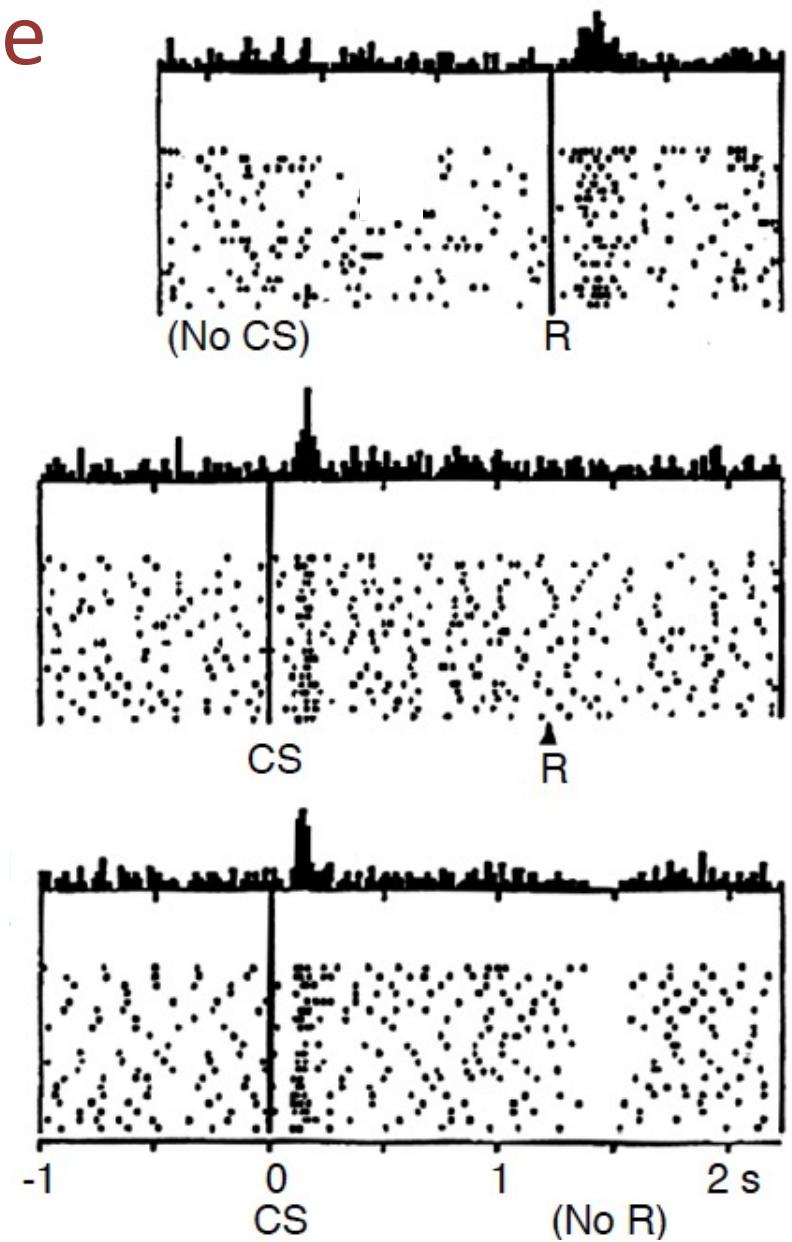




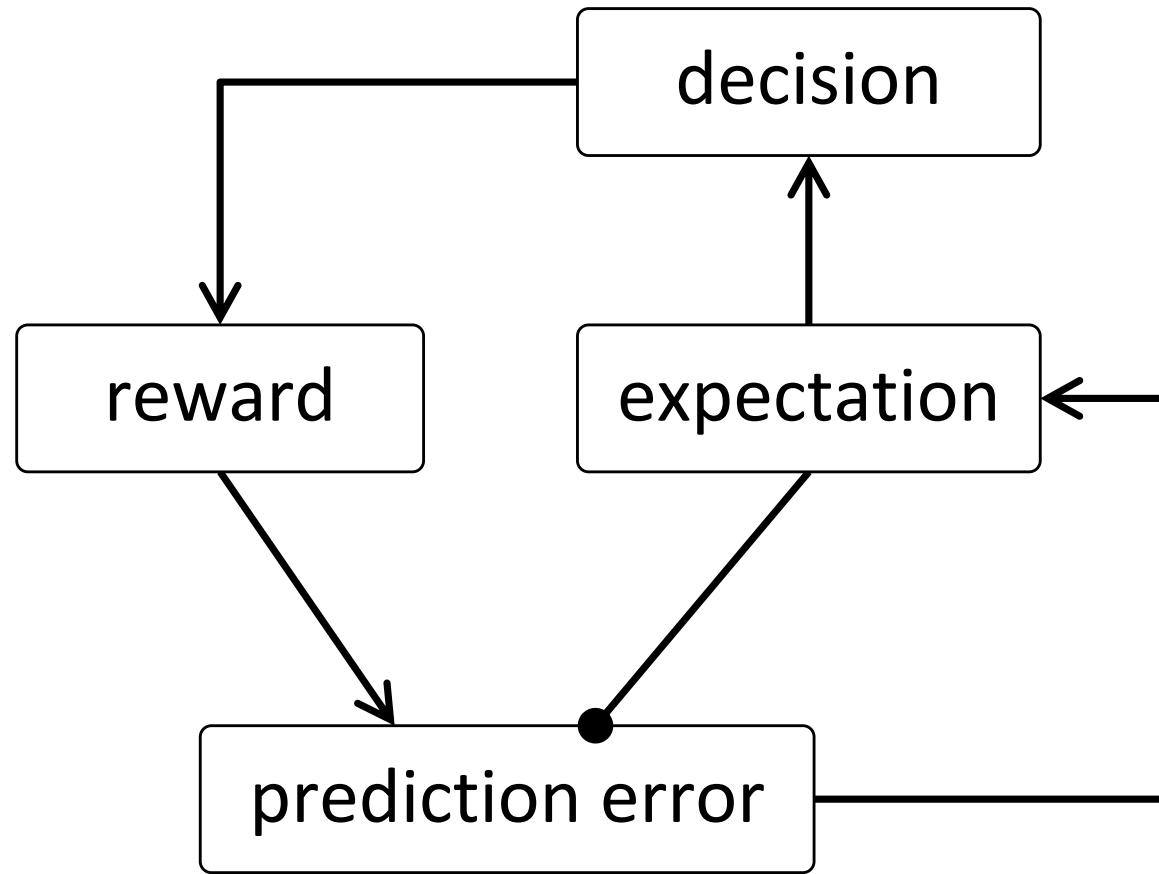


formalizing mood: the famous story of dopamine

- Phasic signals at the time of reward correspond to ***prediction errors***:
$$PE = r - v$$
- Reinforcement learning
Prediction errors can be used to learn ***values***: How much reward do I expect given the current stimulus?
$$v^{new} = v^{old} + \alpha(r - v^{old})$$

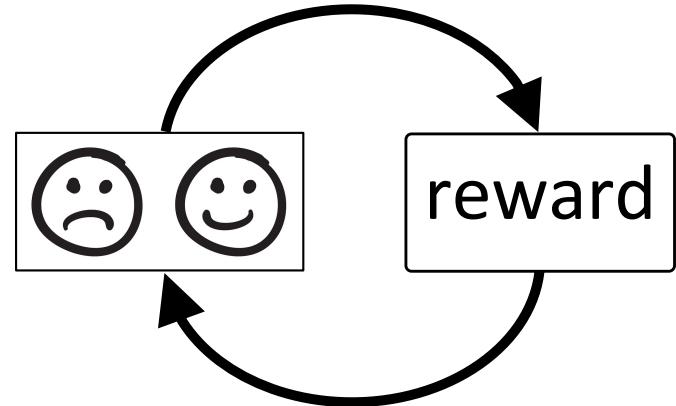


Schultz, Dayan & Montague (1997)



formalizing mood:

$$v^{new} = v^{old} + \alpha(r' - v^{old})$$



mood biases
perception of reward

$$r' = f^m \cdot r$$

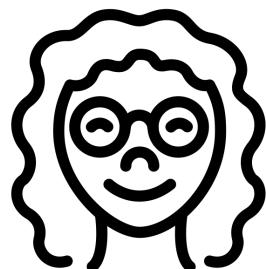
subjective reward

$$m \in [-1,1]$$

mood (fluctuates)

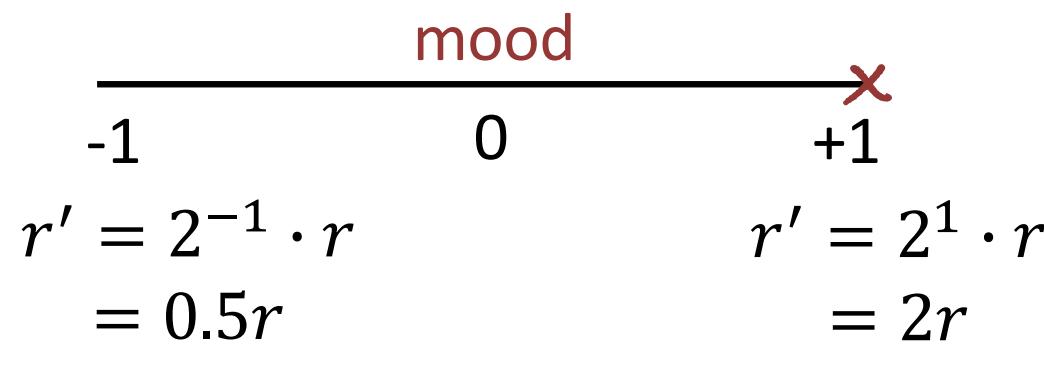
$$f > 0 (\sim 1)$$

Individual difference parameter,
mediates mood bias

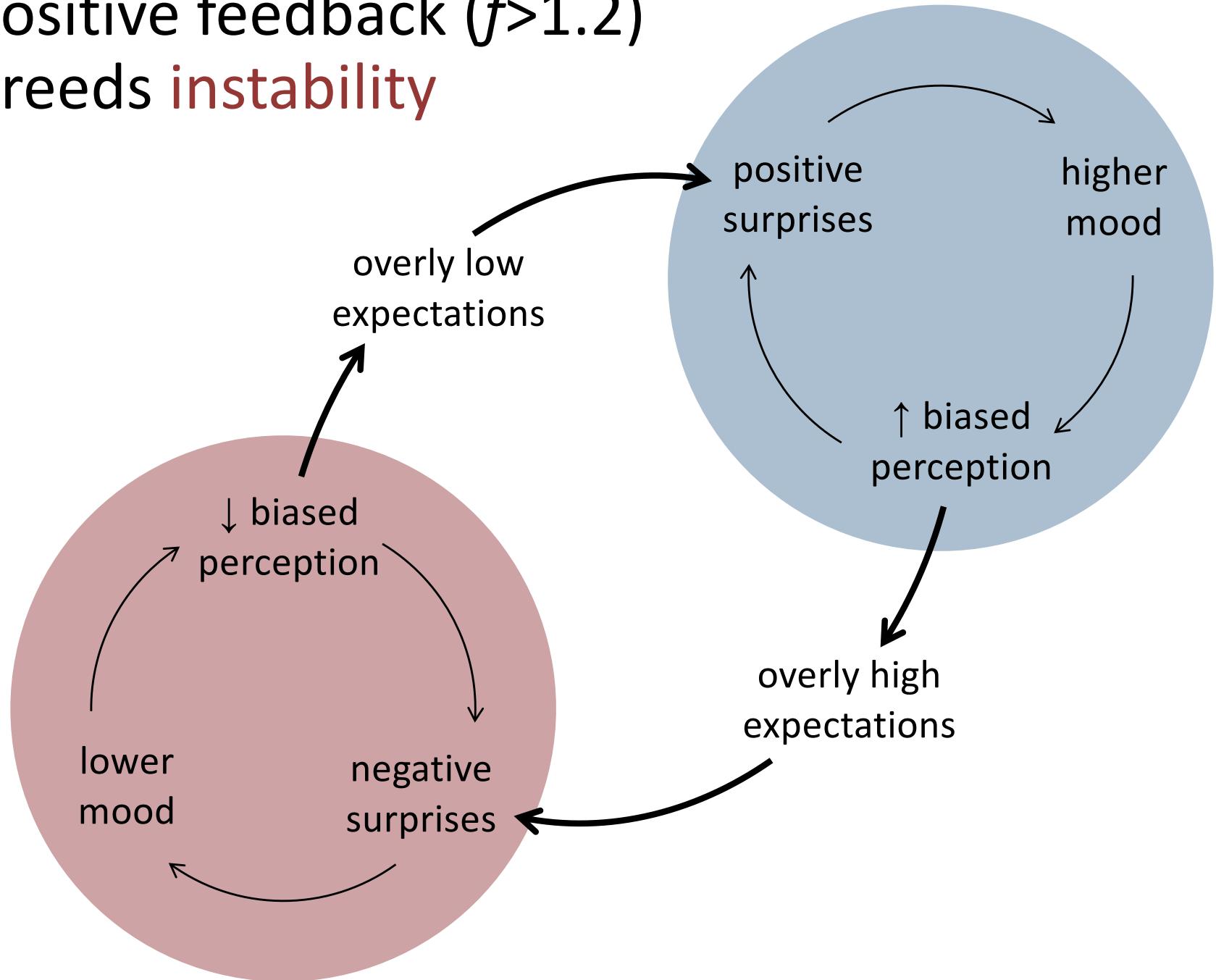


Created by Matt Brooks
from Noun Project

$$f = 2$$

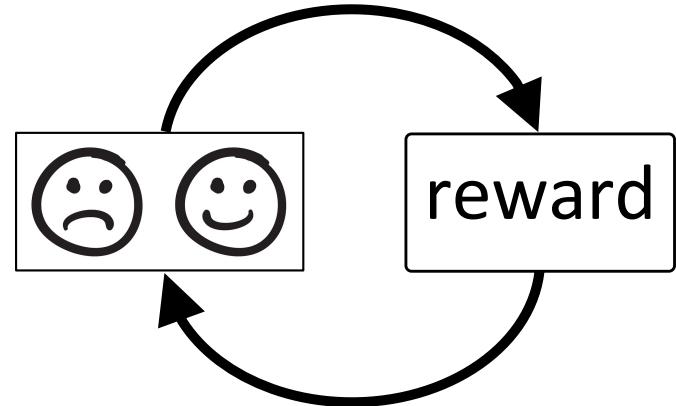


positive feedback ($f>1.2$) breeds instability



formalizing mood:

$$v^{new} = v^{old} + \alpha(r' - v^{old})$$



mood biases
perception of reward

$$r' = f^m \cdot r$$

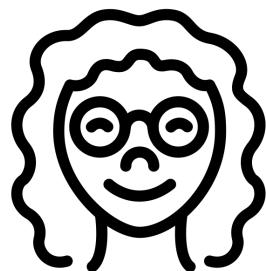
subjective reward

$$m \in [-1,1]$$

mood (fluctuates)

$$f > 0 (\sim 1)$$

Individual difference parameter,
mediates mood bias



Created by Matt Brooks
from Noun Project

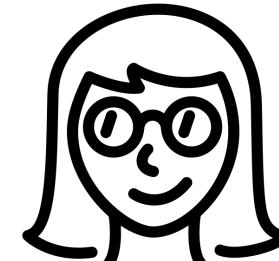
$$f = 2$$

mood

-1

+1

$$\begin{aligned} r' &= \left(\frac{1}{2}\right)^{-1} \cdot r \\ &= 2r \end{aligned}$$



Created by Matt Brooks
from Noun Project

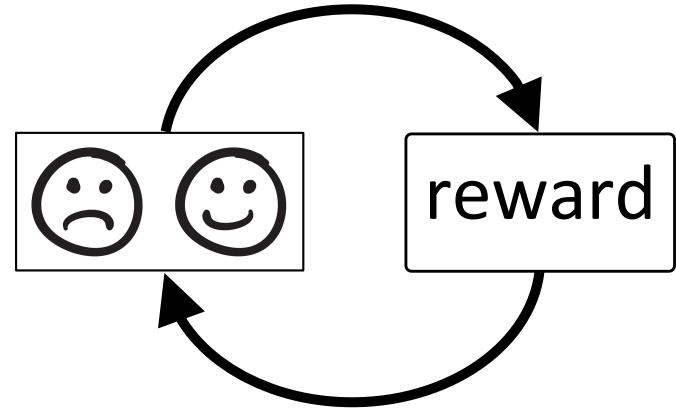
$$f = 1/2$$

$$\begin{aligned} r' &= \left(\frac{1}{2}\right)^1 \cdot r \\ &= 0.5r \end{aligned}$$

Eldar & Niv (2015)

formalizing mood:

$$v^{new} = v^{old} + \alpha(r' - v^{old})$$



mood biases
perception of reward

$$r' = f^m \cdot r$$

subjective reward

$$m \in [-1,1]$$

mood (fluctuates)

$$f > 0 (\sim 1)$$

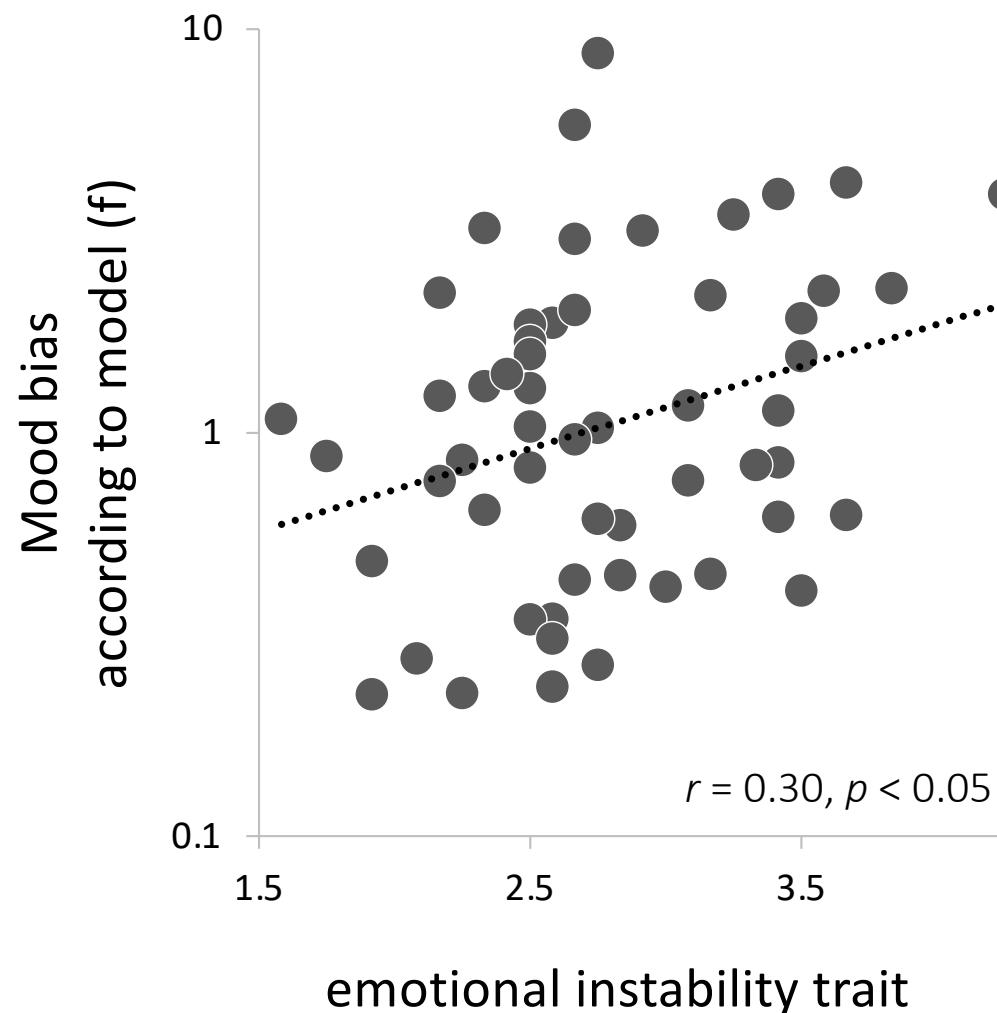
Individual difference parameter,
mediates mood bias

unexpected
rewards
affect mood

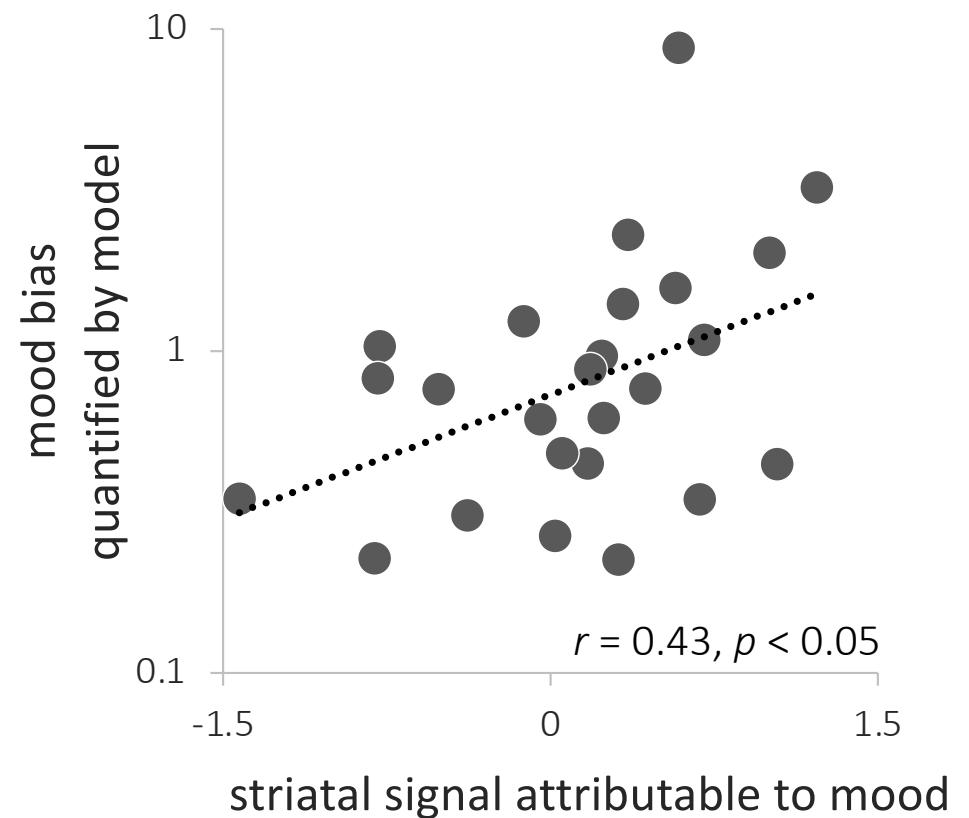
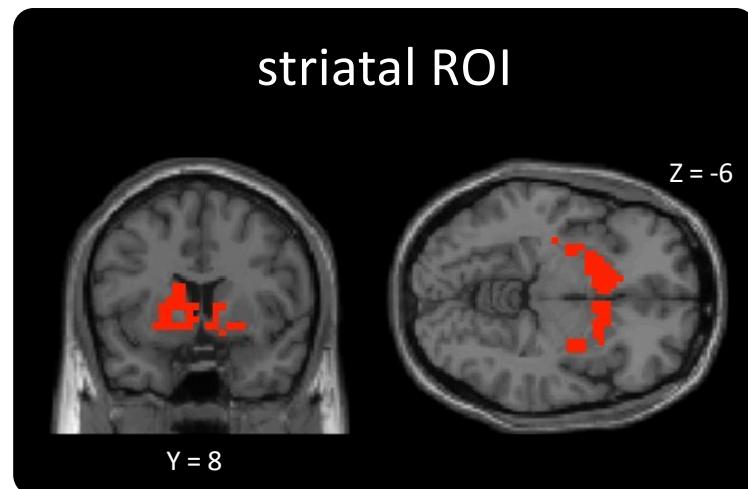
$$h^{new} = h^{old} + \alpha_h(PE - h^{old}) \text{ track historic PE}$$

$$m = \tanh(h) \quad (\text{squash to } [-1,1])$$

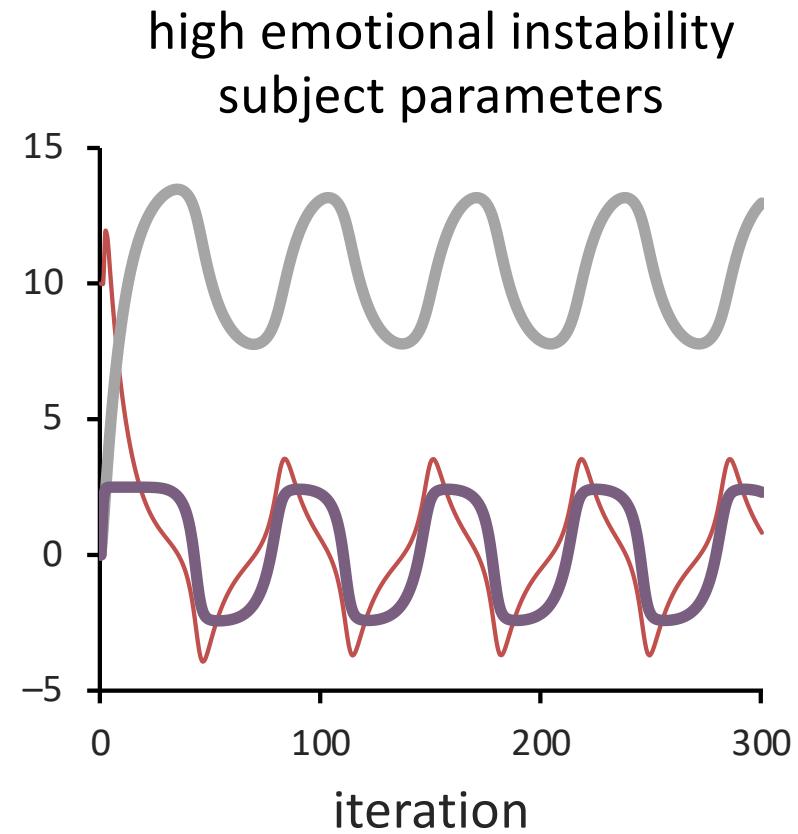
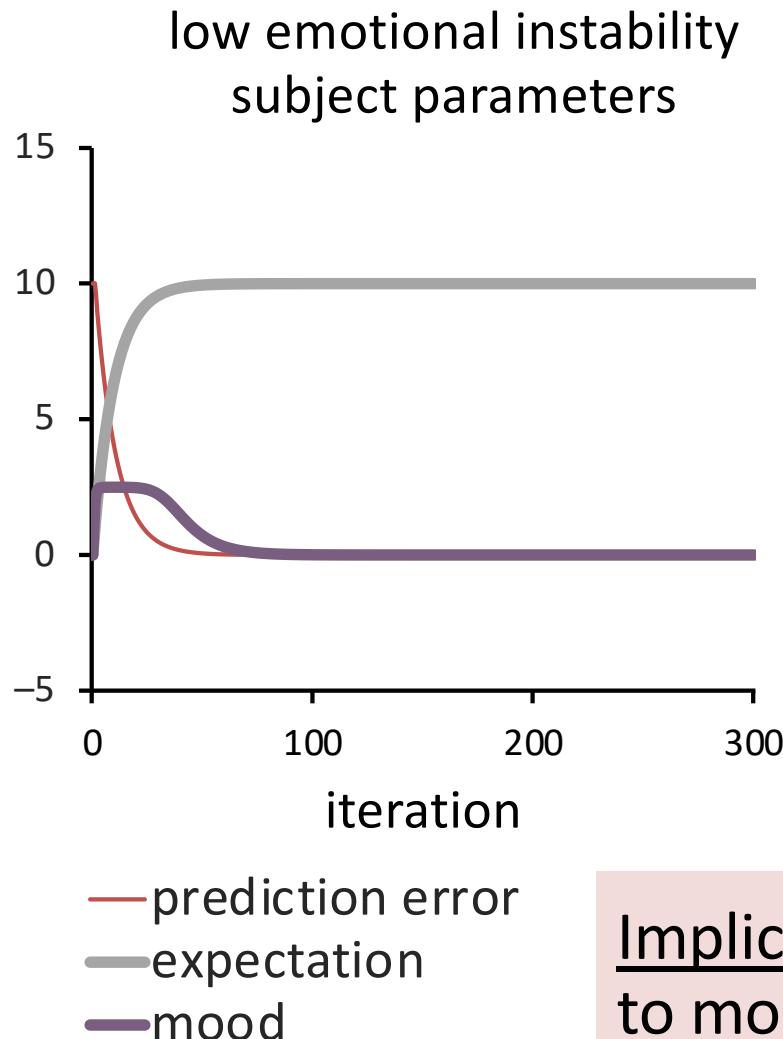
The task & model capture self-reported mood-instability trait



The model explains **striatal response** to reward



reactivity to mood as (dimensional) biomarker for disorders of mood instability?



Implication: high **reactivity to mood** can lead to mood instability (cyclothymia, borderline personality disorder, bipolar disorder)

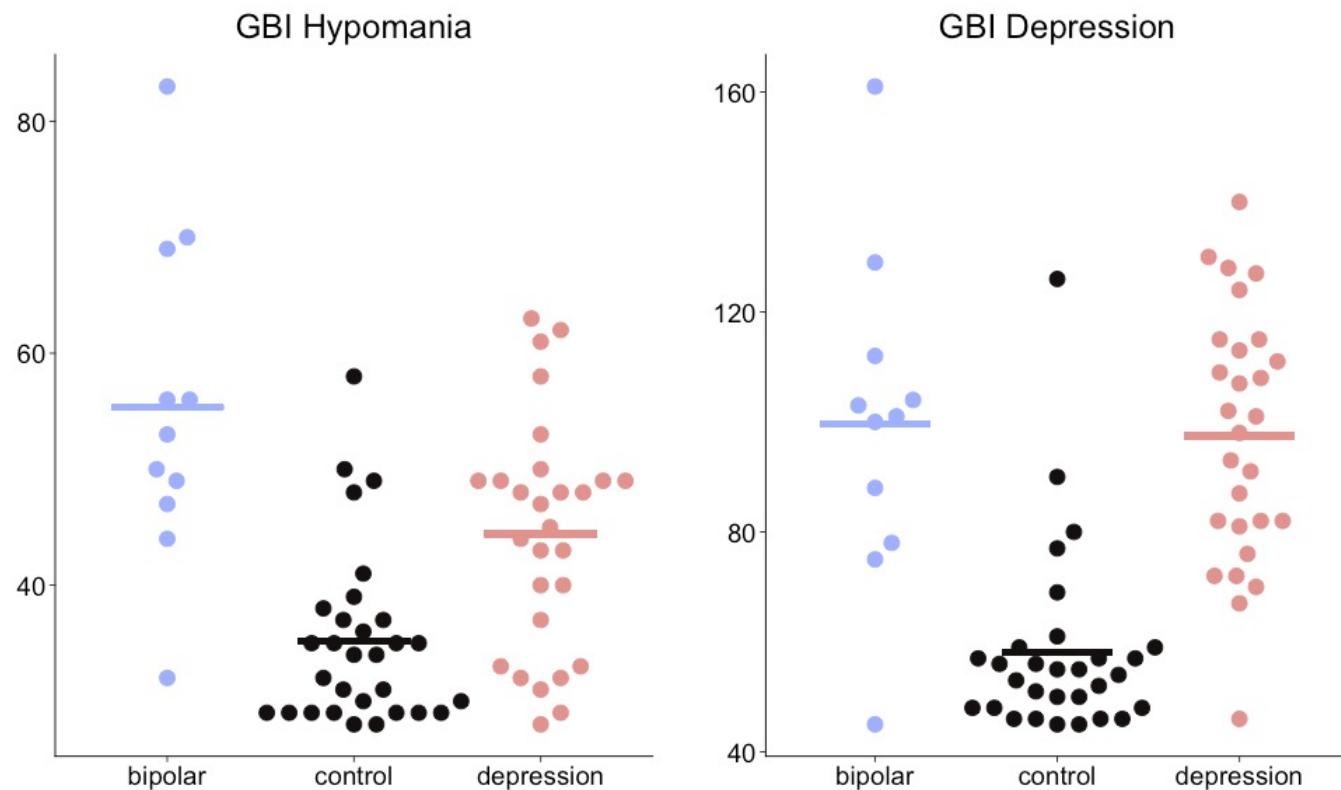
Is this framework relevant for mood disorders?

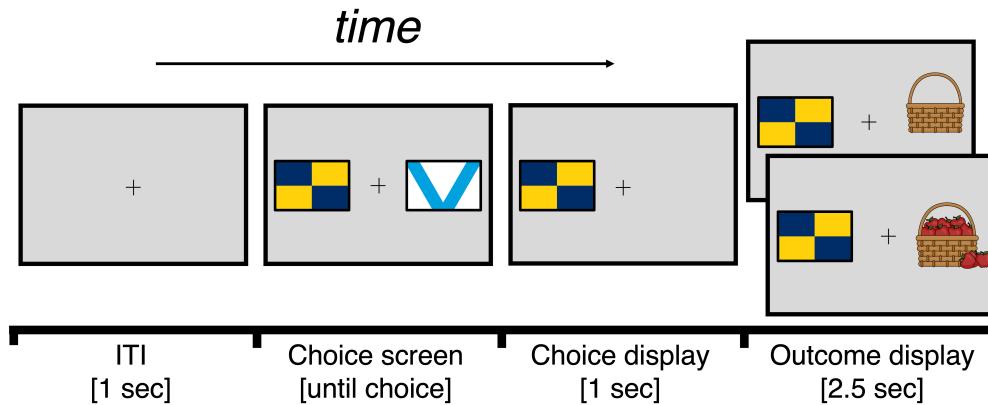
N = 94

- 42 lifetime depression
- 17 lifetime bipolar
- 35 matched controls

Exclusion criteria:

- Any psychotic features
- Any substance abuse
- Any neurological conditions





Learning block 1

Choose between new orchards	Wheel of Fortune (lose \$7)	Choose between new orchards	Choose between old orchards
75% 25%		75% 25%	

Learning block 2

Test block

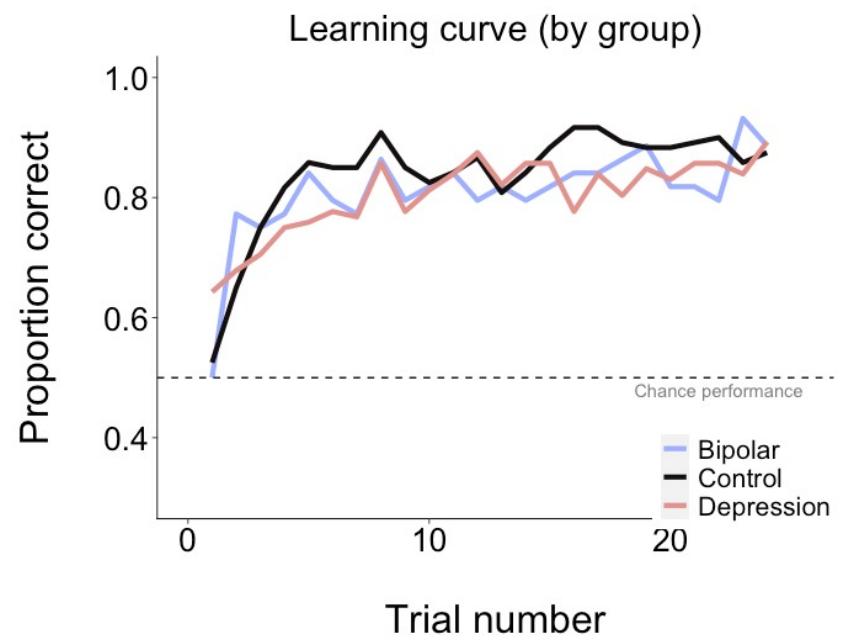
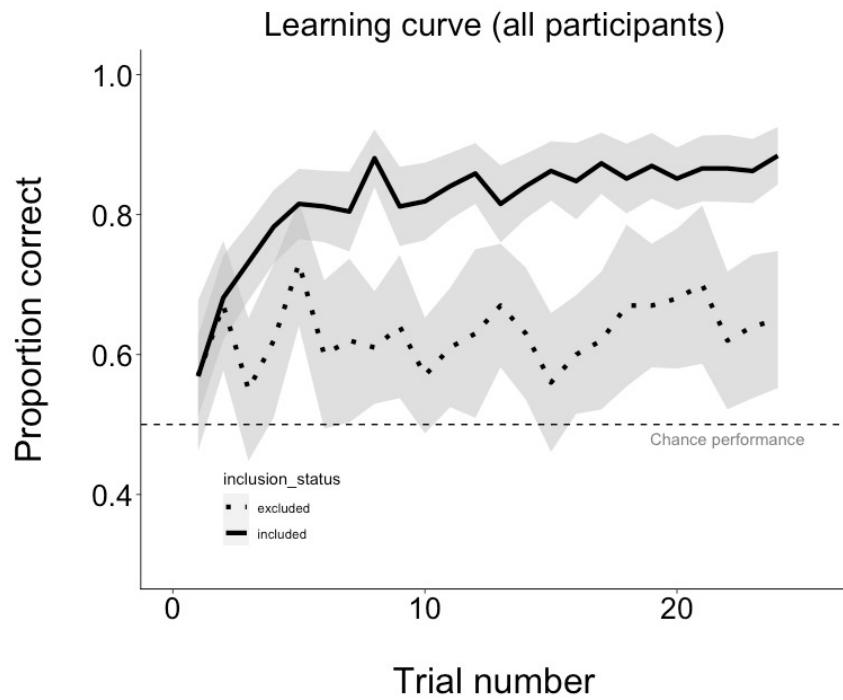
Learning block 1

Choose between new orchards	Wheel of Fortune (win \$8)	Choose between new orchards	Choose between old orchards
75% 25%		75% 25%	

Learning block 2

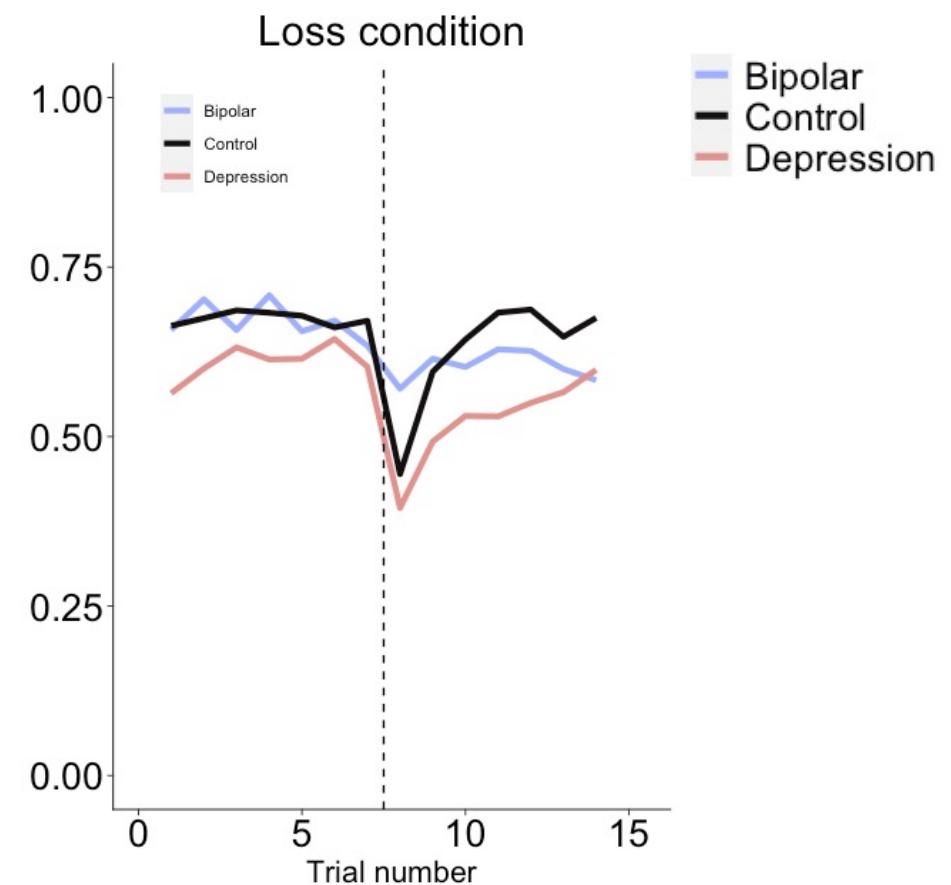
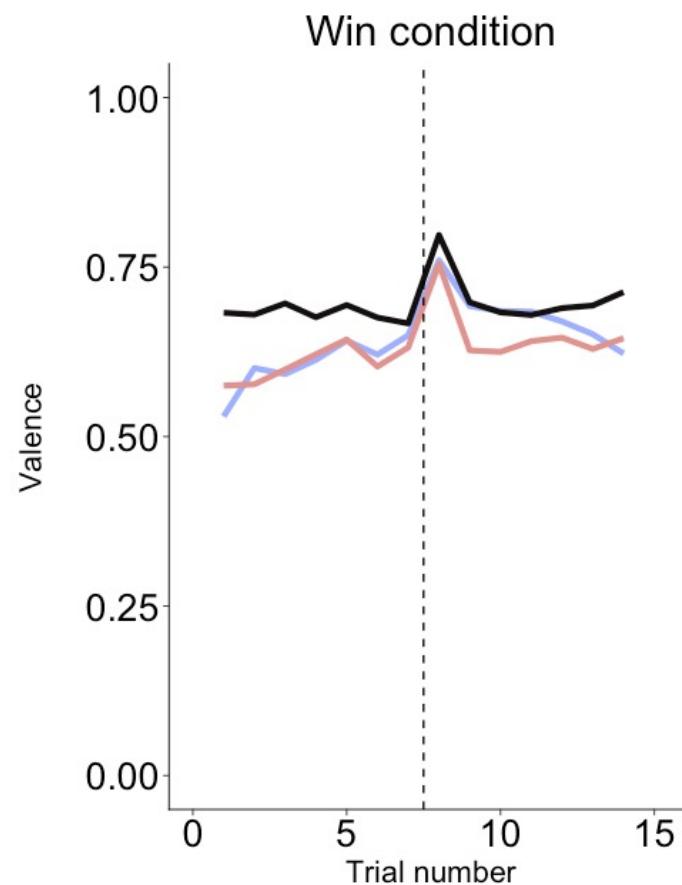
Test block

Everybody learns the task (after exclusions)

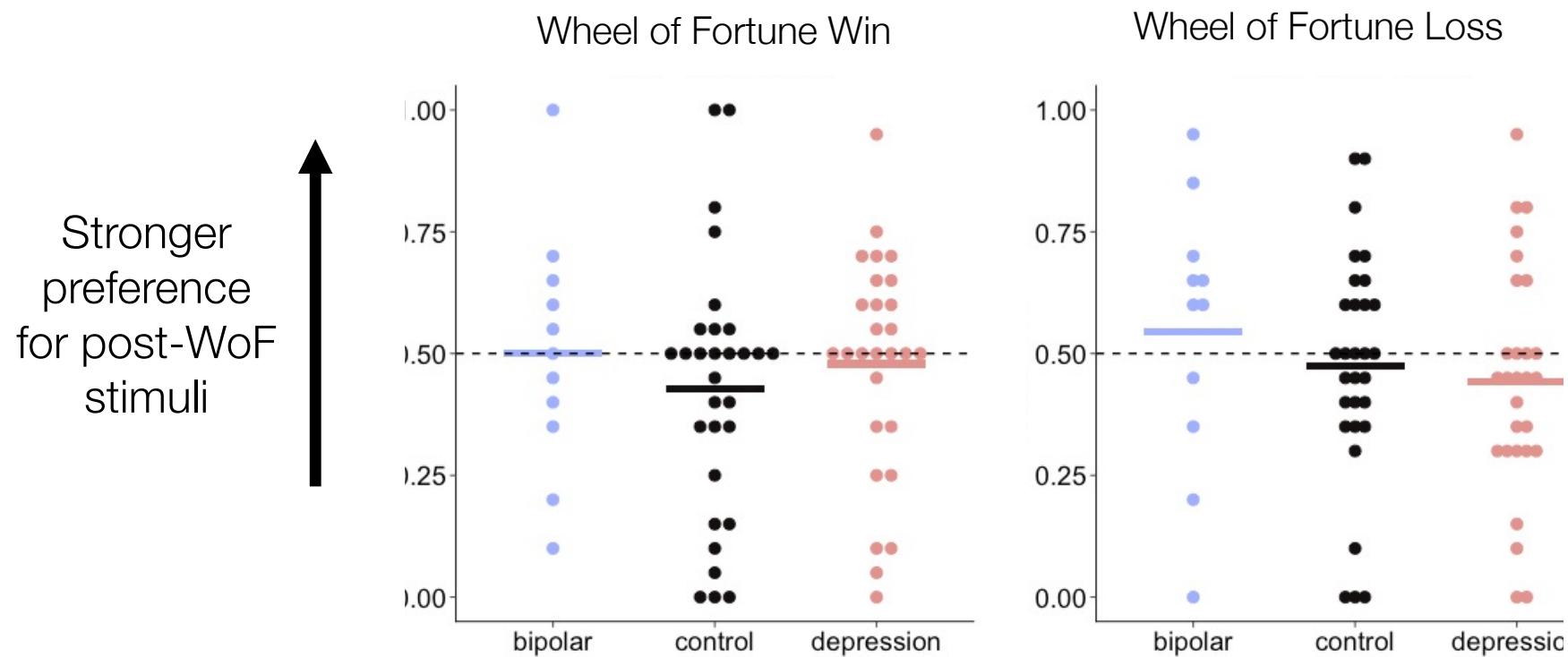


No difference in overall learning between groups, $\chi^2(2) = 0.28, p = .87$

Please rate your overall sadness/happiness at this moment.



No overall effect of WoF on preferences across or between groups



No between-groups differences in WOF effects: $\chi^2(2) = 1.71, p = .42$

Modelling the data

Model 1: Standard Q-learning

$$\Delta Q(s_t, a_t) = \eta \cdot (r - Q(s_t, a_t))$$

Model 2: Q-learning with a symmetric effect of mood

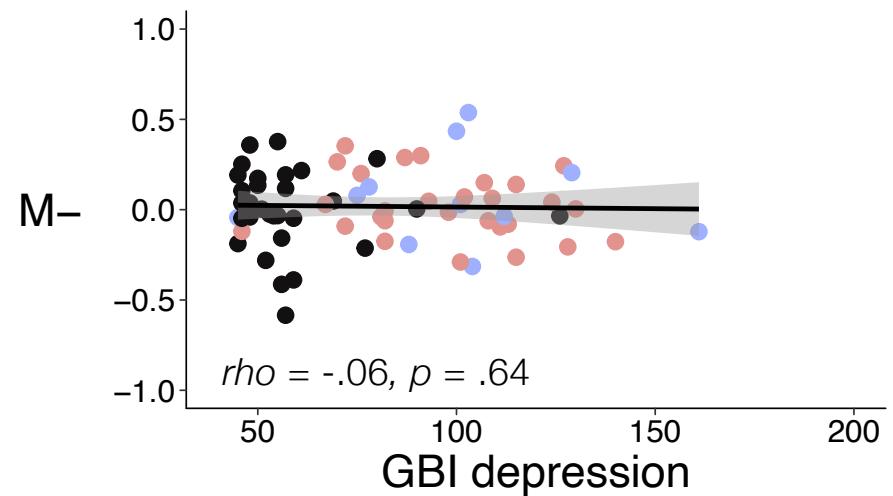
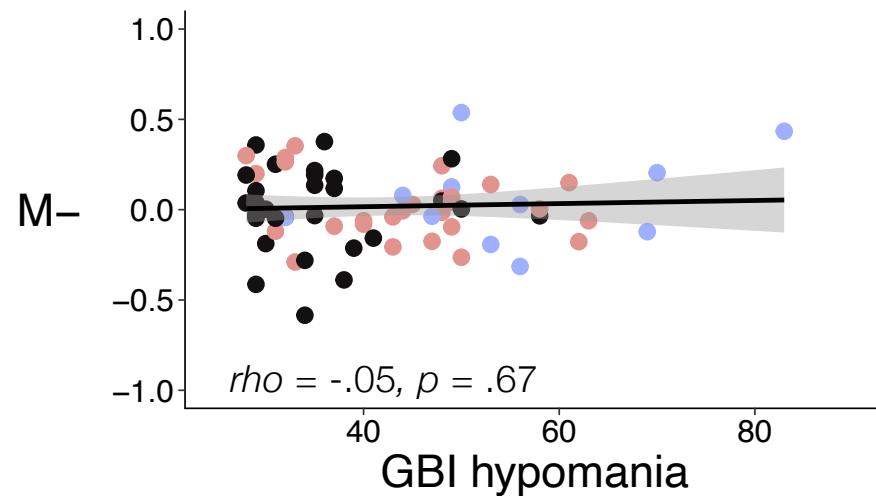
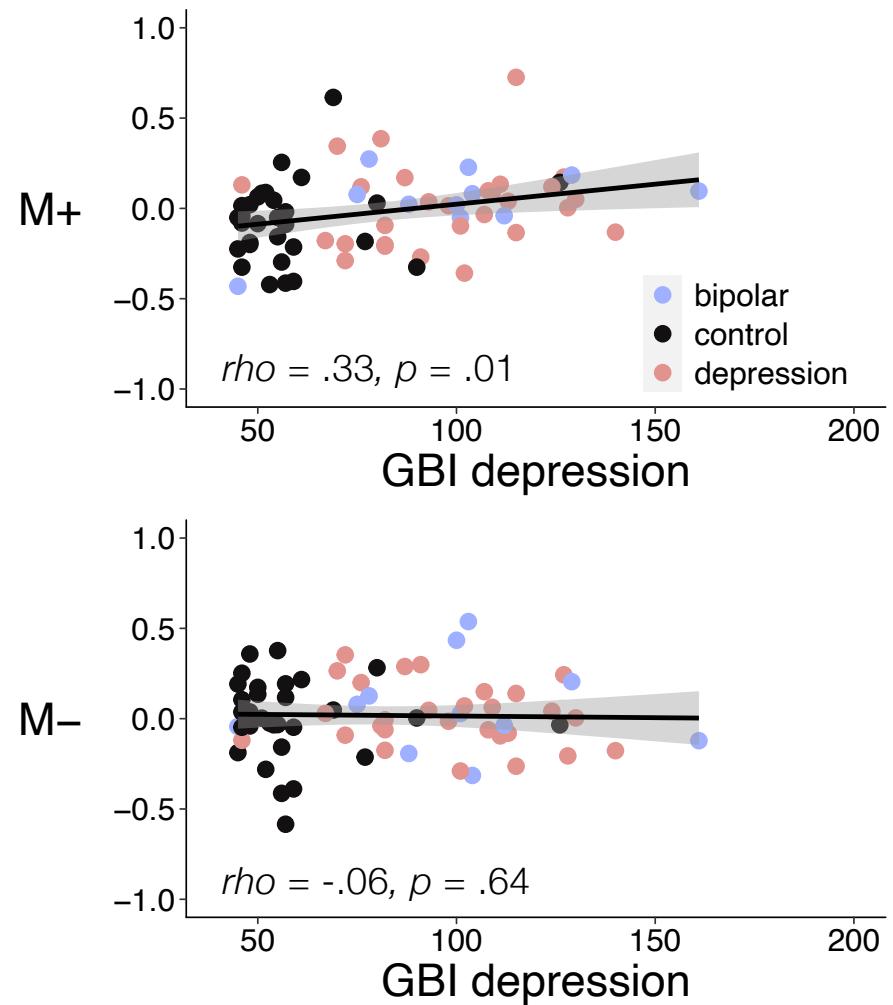
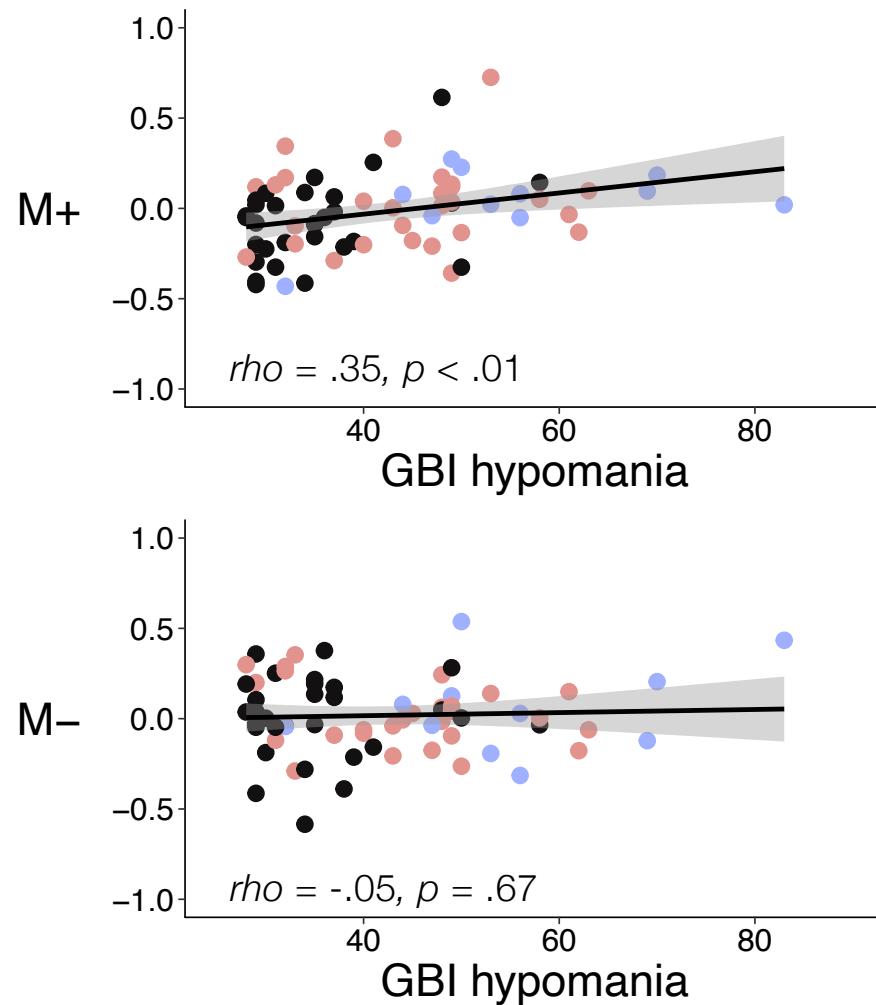
$$\Delta Q(s_t, a_t) = \begin{cases} \eta \cdot (r - Q(s_t, a_t) + M) & \text{After Wheel of Fortune win} \\ \eta \cdot (r - Q(s_t, a_t) - M) & \text{After Wheel of Fortune loss} \\ \eta \cdot (r - Q(s_t, a_t)) & \text{First block} \end{cases}$$

Model 3: Q-learning with an asymmetric effect of mood

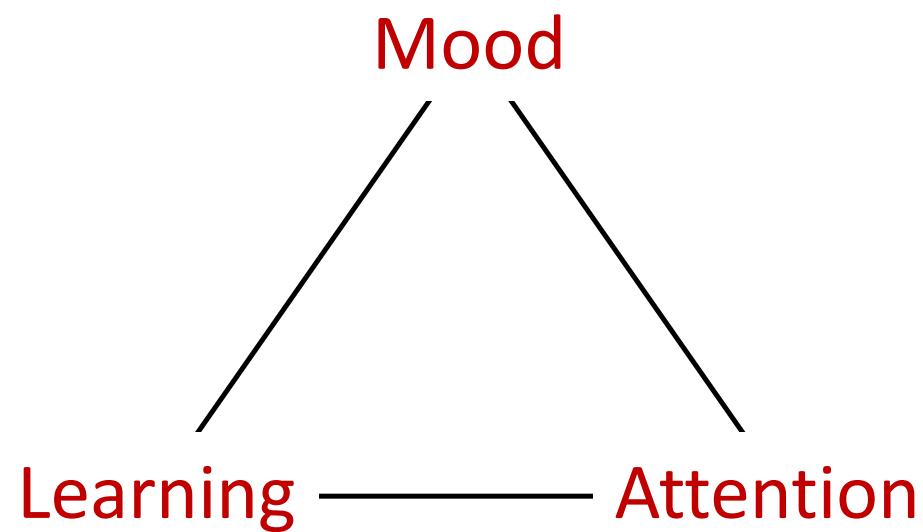
$$\Delta Q(s_t, a_t) = \begin{cases} \eta \cdot (r - Q(s_t, a_t) + M^+) & \text{After Wheel of Fortune win} \\ \eta \cdot (r - Q(s_t, a_t) + M^-) & \text{After Wheel of Fortune loss} \\ \eta \cdot (r - Q(s_t, a_t)) & \text{First block} \end{cases}$$

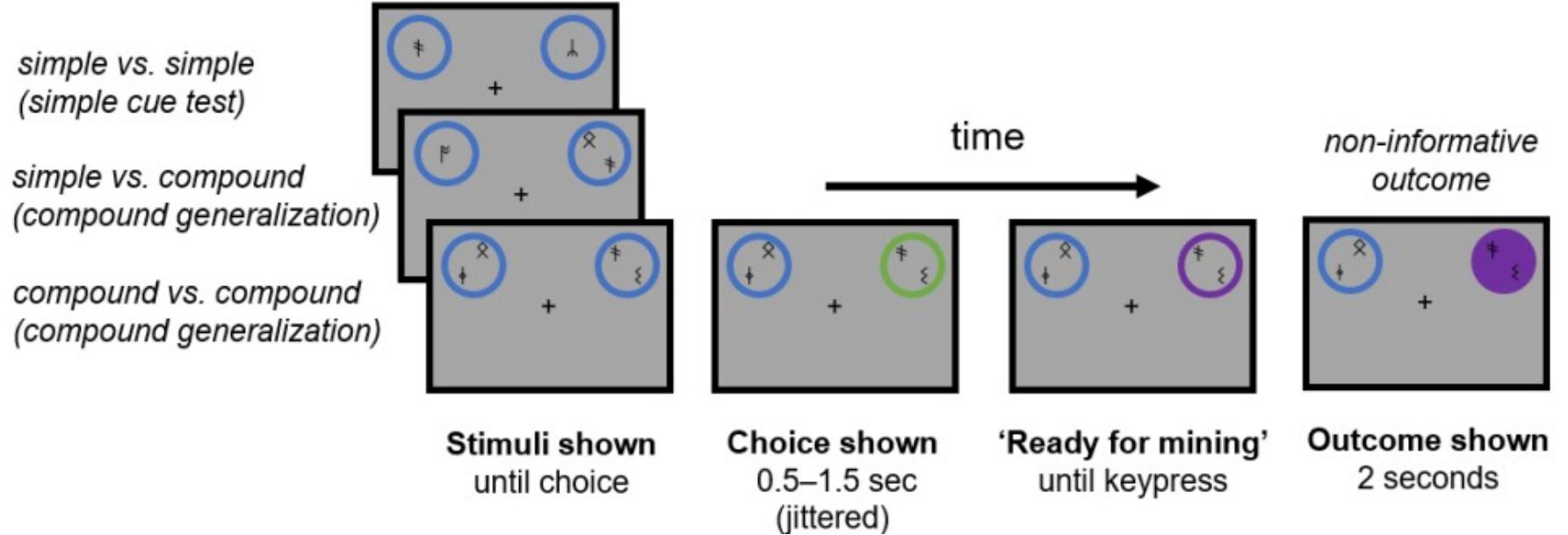
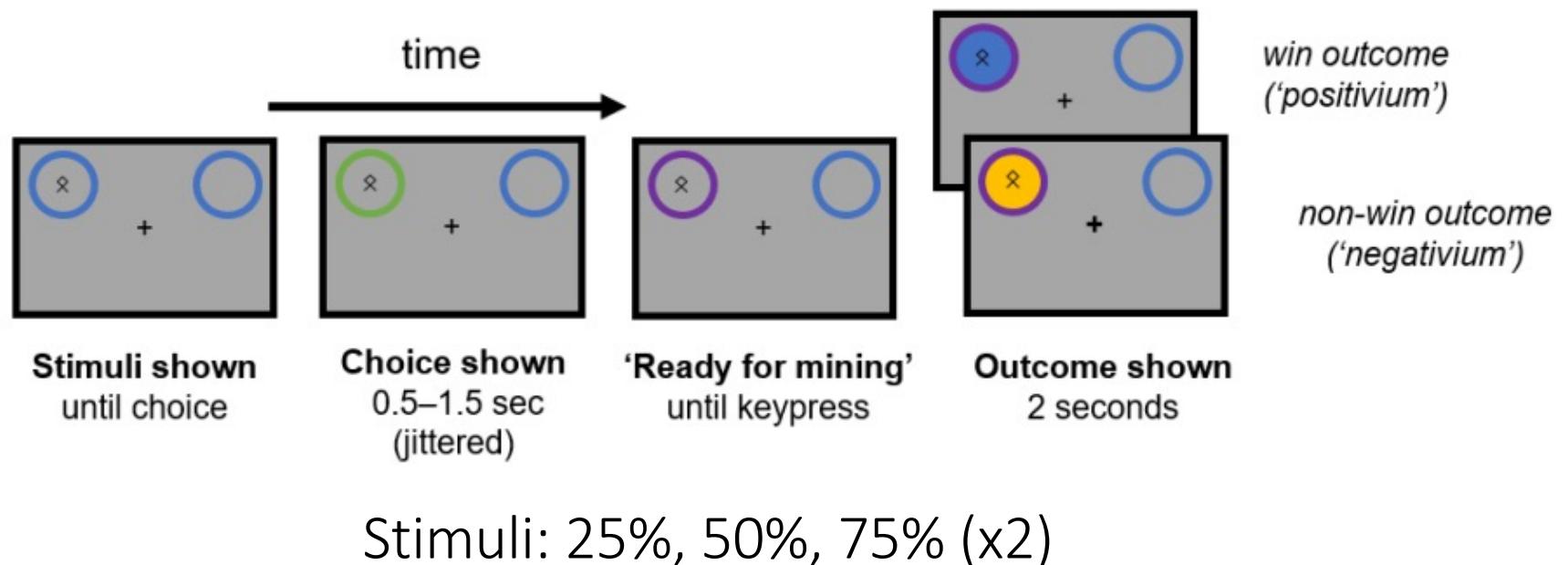
	WAIC	Δ WAIC (SE)
Model 1 (no effect of affect induction)	9809.9	573.4
Model 2 (symmetric effect of affect induction)	9643.2	406.7
Model 3 (asymmetric effect of affect induction)	9236.5	0

Correlations between mood pathology and effects of positive affect induction



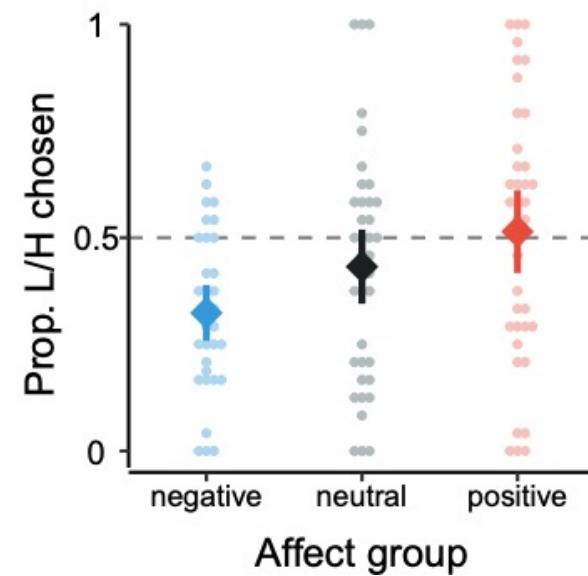
The pervasive effects of mood on decisions



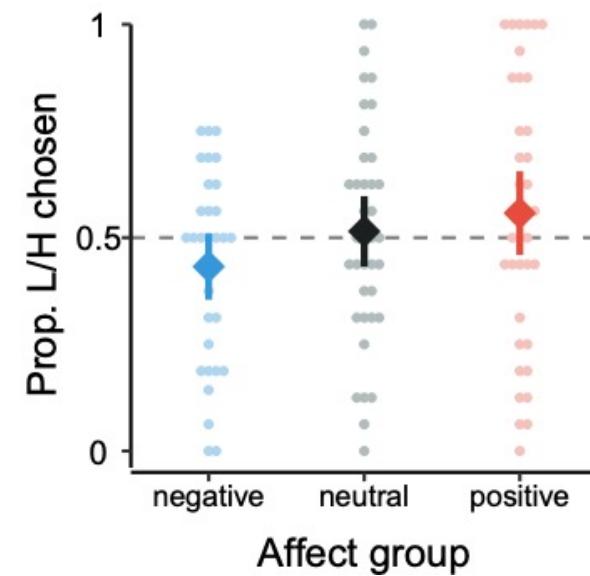


Test: 75%/25% compound versus 50%

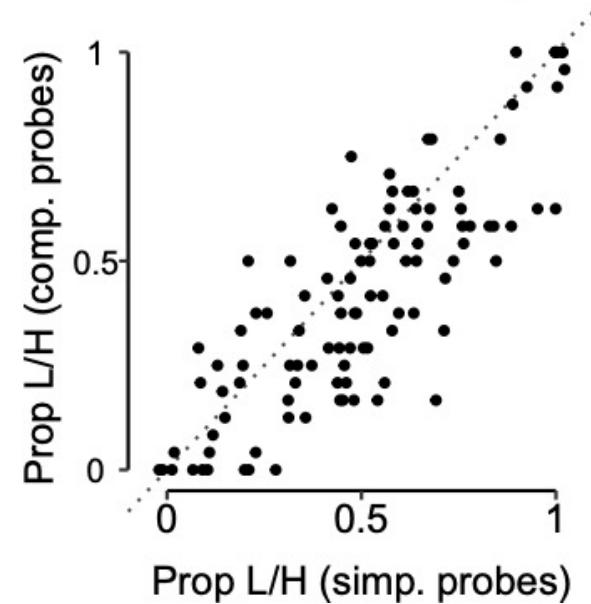
D. Compound probe trials

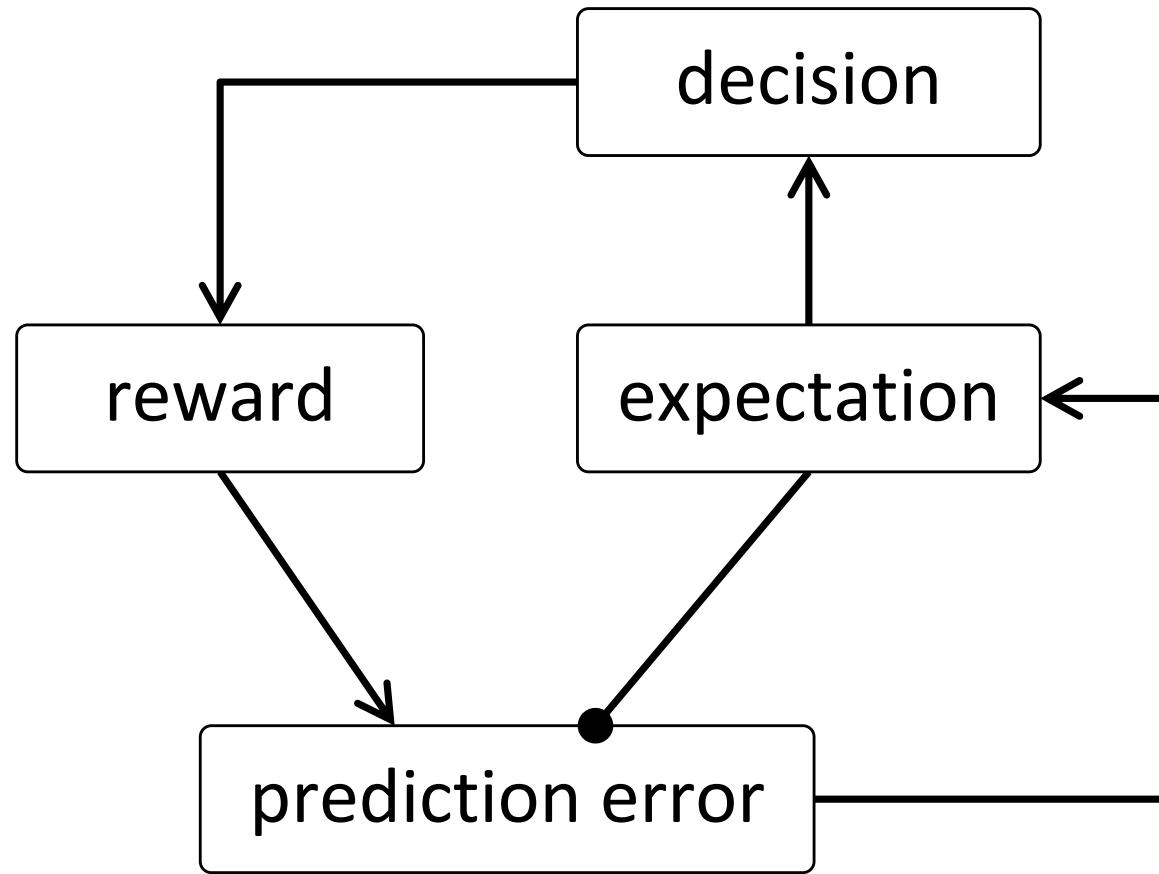


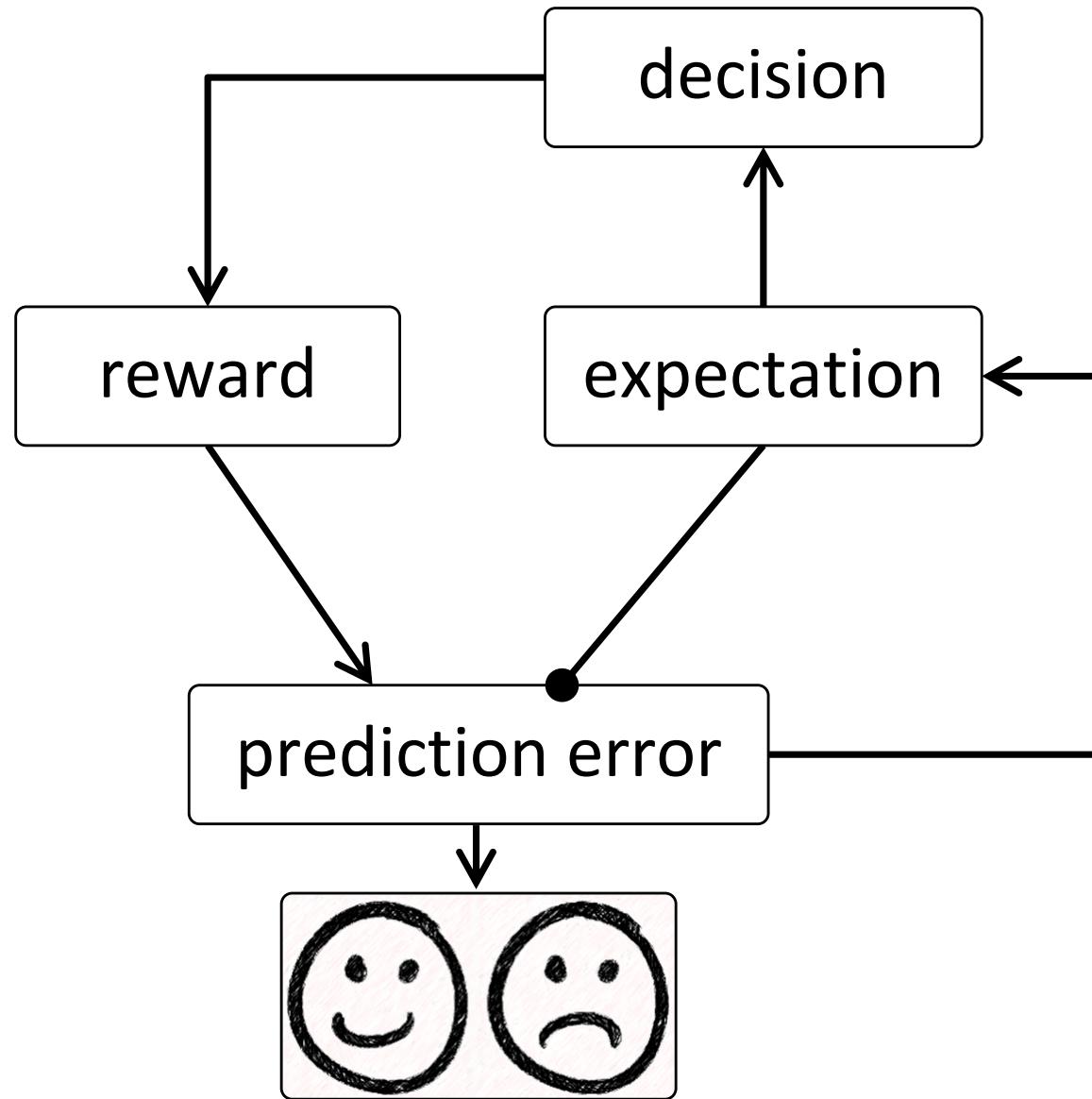
E. Simple probe trials



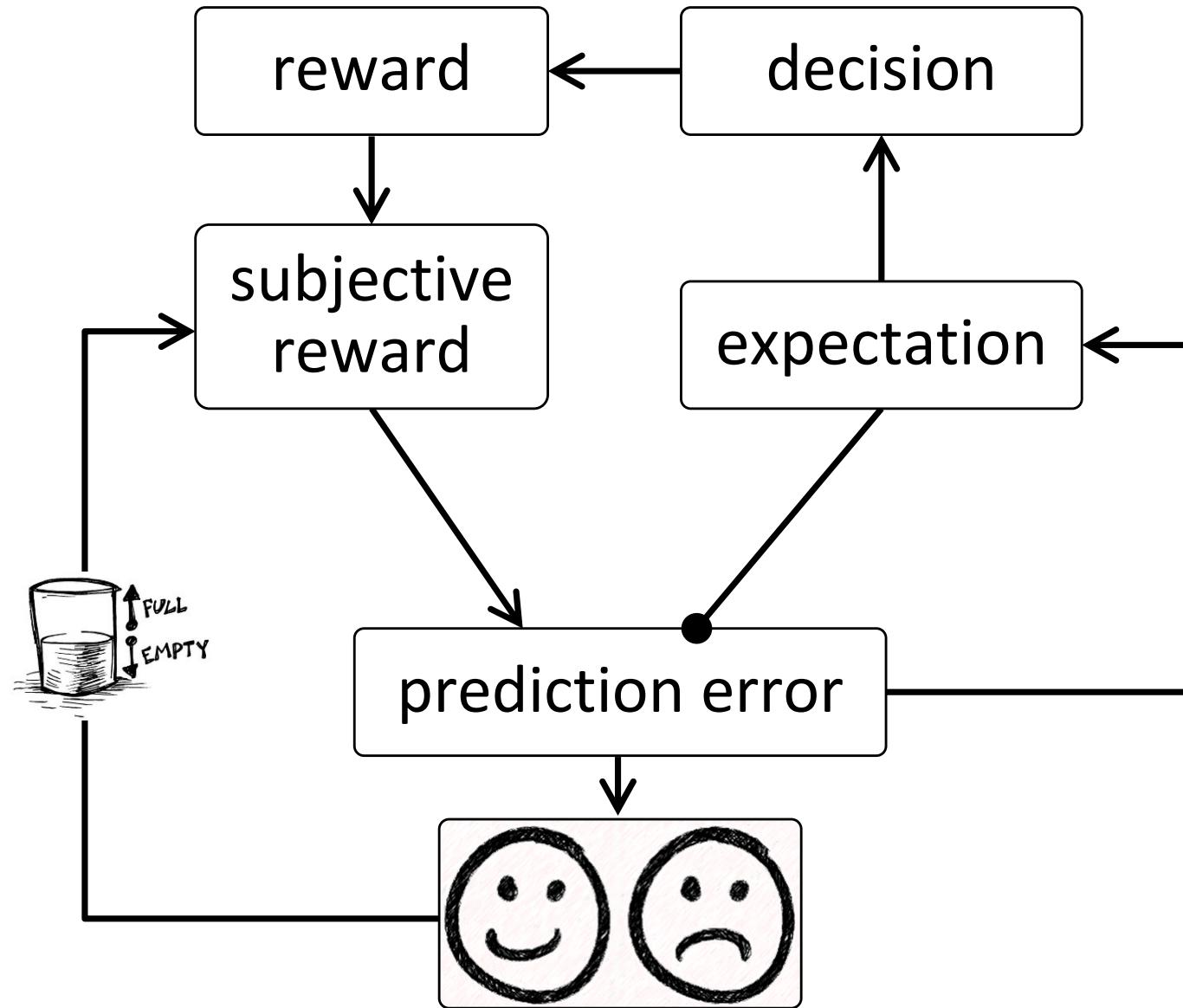
F. Probe trial consistency







Mood-biased reinforcement learning





Dan Bennett

+Sam Zorowitz

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Alfred P. Sloan Foundation

NIH (NIDA, NIMH)

NSF

Ellison Medical Foundation

John Templeton Foundation

Human Frontiers Science Program

Army Research Office

Intel Labs



Rutgers-Princeton Center for
Computational **Cognitive** **N**euro-**P**sychiatry

